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Preliminary Remarks: Status of the project

The goal of the Very Long Term Energy-Environment Model (VLEEM) Project is to establish a methodology and to develop tools for energy system modelling over one century. In VLEEM I major steps in this direction were realised. In VLEEM II, the tools have been completed and validated while developing the case studies, but their formal integration in a single model of the “great all” has been abandoned for practical and conceptual reasons.

Special emphasis has been put in VLEEM II on energy efficiency and end-use technologies, which were both identified as priorities in VLEEM I. This represents an attempt to react to remarks and critics received after VLEEM I, although assessing end-use technologies and related energy efficiency potentials over one century remains a big challenge. Neither all end-use technologies, nor all energy services have been assessed for due to the enormous number and variety of options; the emphasis has been put on bulk material production and transport, because they constitute the core problem in the very long term as regard the use of fossil fuels and the related emissions of GHG.

Monographs about future energy carriers and conversion technologies have been further developed and improved; although especially demanding assuming the very long time horizon, these monographs have proved to be very useful to provide boundaries to the case studies.

The three cases of energy technology clusters have been further worked out at different level of detail in VLEEM II. Although it has been possible to process comprehensively the quantitative results only for Europe, a lot of detailed results on the needs of energy services and useful energy requirements, including energy efficiency, have been processed for all world regions up to 2100.

Already, from the studies carried out in VLEEM II, and from the quantitative results obtained, some preliminary robust findings emerge as to energy RTD challenges, priorities and agenda. A lot of work remains nevertheless to be done to come out with sound visions of the possible energy worlds of the end of the 21th century.

1. Chapter 1: Introduction

The 21st century will have to face tremendous challenges related to the climate change, the depletion of fossil fuel resources and the management of nuclear wastes. The development of the technologies necessary to face these challenges and the long reinvestment cycles especially for buildings, power generation and energy intensive manufacturing, require to consider all these issues over the whole century, in the broad context of sustainability.

The VLEEM project has been designed to address these challenges, combining two methodological innovations which are imposed by the very long time-frame:

- an innovative approach of the very long term future, particularly suitable for RTD strategies elaboration in the context of sustainability: the back-casting approach;
- a re-foundation of the energy-environment modelling structures, in order to properly assess very long term modification of social and cultural preferences and technology evolution dynamics in relation to them.

1.1 Sustainable energy visions for decision making over the very long term¹

"Our Common Future" ("Brundland report) defines a sustainable development as *"a development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

This definition considers three dimensions in sustainability: economic, social and environmental .

In VLEEM , this has been reformulated as follows: under which conditions, about the overall human future context, the debate on sustainable energy systems in the very long term remains meaningful. Which key context elements would make personal and social life "enough" acceptable throughout the world in one century from now, from cultural, social, economical and geopolitical points of view, so that no major social, sanitary, civil and military geopolitical irreversible catastrophes occur all along the century. Acceptability in the VLEEM context is understood in relation to four simplified socio-cultural functions : providing, in quality and in quantity, enough food, shelter, self accomplishment and paid work to human beings.

1.1.1 How to "quantify" sustainability for very long term energy studies?

Criteria and indexes need to be described, which translate the general definition of "sustainable development" into practical terms.

The social and economic dimensions of sustainability can hardly be defined with precise quantitative criteria. Different possible pictures of the world can be elaborated for 2050 and 2100 through consistent scenarios. The overall consistency of these scenario can be assessed

¹ For more details on sustainability in VLEEM, see "Accounting for sustainability in VLEEM - A synthesis" in www.VLEEM.org

more or less scientifically and one has to admit that a scenario which is possible from the socio-economic viewpoint is a sustainable one over the time period considered.

Things are different with the environmental dimension of sustainability, in particular when it refers to a sectoral issue like energy. Here we have to decide what is acceptable on the very long term, and what is not, from a pure ethic viewpoint. In other words, we have to settle pre-defined quantitative criteria measuring precisely the red line not to be over-passed.

To be effective for decision making, these criteria should in any case result from a negotiation procedure where all stakeholders must be involved to actually properly balanced the short term drawbacks on economy and society of the decision with the environmental benefits for the future generations to come.

The climate change issue

The consequences of the green house gases emission on the climate over the long and very long term are still a matter of tough discussions among scientists, and between scientists and policy makers. Depending on the scenarios established by the meteorologists, some people would appreciate the consequences of the climate change, other not at all. Nevertheless, the fundamental equity dimension behind the sustainability principle obliges to consider that a red line actually exist, beyond which human, ecologic, economic and social disasters are likely to happen in various parts of the world, which could be and must be avoided.

The international community, both scientists and decision makers, is now fully aware of the problem and tries to find an appropriate trade-off between the necessity to limit the green house gases emissions below the red line, and the economic and social costs involved in the various parts of the world; between those who consider that the red line should adapt to the short-medium term economic constraints, and those who consider that the economic and social effort should adapt to the red line.

The SRES scenarios adopted by the IPCC to figure out sustainable futures as regard the climate change thus consider different levels of constraints on world emissions of green house gases: the goal is to provide appropriate information for the democratic debate and the international negotiations, not to say “the truth” on this issue. What appears the most important for the IPCC is the ability to evaluate all the consequences of these emissions (physical, economic, ...) at the different emission thresholds, and how these thresholds are obtained, rather than trying to “discover” and “propose” the “best” threshold.

In VLEEM, the debate is attacked from the future, consistently with the back-casting approach. A CO₂-concentration stabilisation has to be reached at some point, if the climate system should not become completely unstable. This requires that at some point in the future (next 100-200 years) the emission level from fossil fuel combustion has to become roughly zero. This sets the goal: only zero emission technologies from some point in time on. This is still a too soft statement to develop precise pictures of the future. The final goal will certainly be set by a negotiation process, it will strongly depend on the overall political situation, the geographical distribution of impacts and the economic situation and especially the economic disparities and last but not least on the scientific evidence to couple certain impacts to greenhouse gas emissions. This implies that the final emission goals have to be set during the analysis phase in a consistent manner. If it becomes evident that certain weather phenomena (especially extremes, like the summer 2003, or the floods in central Europe in

2002) are strongly coupled to men made greenhouse gas emissions, then more stringent emission goals seem feasible.

The criteria adopted in VLEEM to support the quantitative outlook is defined somehow in the spirit of the existing international negotiations (i.e. Kyoto Protocole up to 2008-2012): rather than fixing an absolute limit to global emissions or per capita emissions, we assumed a continuous effort expressed as a percentage reduction every ten years after a certain development level is reached, for all countries of the world.

For industrialized countries (OECD + CIS), the overall target is to reduce the GHG emissions related to energy by 10% every 10 years in average, starting in 1990. The weaker constraint between 1990 and 2008-2012 (Kyoto Protocole) is assumed to be compensated by higher constraints after 2012.

For developing countries, the same effort is assumed to be imposed once the country has reached a GDP/capita equivalent to the average level of industrialized countries in 1990, at purchasing power parity.

The nuclear issue

Nuclear is a rather controversial issue as regard sustainability. Connexions between civil and military uses of nuclear are strong, and existing nuclear weapons could almost destroy all life on earth. Radiotoxicity of nuclear wastes can last as long as several thousands of years, creating a permanent threat on future human beings, which is exactly at the opposite of sustainability principle, at least on its ethic dimension. But mastering the nuclear energy is also a tremendous chance for the human kind to abolish the resource and environmental burdens that fossil fuels put on the human development for this generation and many of those to come.

Today's nuclear energy is intrinsically not sustainable. This is the first principle to be admitted, otherwise there is no limit to be put on the development of the nuclear energy, at least as much is needed to cope with other environmental sustainability criteria.

The second principle is that nuclear energy could be made sustainable, thanks to technological development likely to make it possible to break the link between civil and military uses, and to destroy the very long term radiotoxicity of the nuclear wastes or to eliminate such wastes. Obviously transmuting or fusion belong to these categories. This principle has also to be admitted, otherwise there would be no future for nuclear in a sustainable world.

If nuclear is to be sustainable, there cannot be any more objections for any country to have access to nuclear, making this country escaping to the environmental and economic burden that increasing scarcity (and then rising prices) and carbon content (and then rising limits on quantities) of fossil fuels will put. In that respect, it could certainly contribute to a faster and long lasting socio-economic development (in the broad sense) of the planet. This has two consequences:

- the unit sizes of nuclear units should be compatible with most of the sizes of the national energy grids,
- the control of nuclear operations safety should not be different from any other industrial activity, and should not impose any particular organisation and governance of the society beyond what is currently accepted in democratic industrial societies.

Sustainability does not mean that nuclear should become totally harmless, but that immediate industrial risks (accidents in operation, wastes processing and storage, proliferation,...) may be

balanced with immediate socio-economic benefits in the one side, and that reducing long term environmental burden can be balanced with immediate socio-economic efforts in the other side.

As a consequence, VLEEM has adopted four qualitative criteria to define what sustainable nuclear solutions should be:

- 1 - No major accident “physical possibility” (i.e. accident releasing significant quantities of long life radiotoxic elements)
- 2 - No proliferation “physical possibility” (i.e. no bridge between civil and military applications)
- 3 - A zero long-lived high level waste inventory
- 4 - A real contribution to development (i.e. accessible for all)

Renewable energy issues

One of the main sustainability problems raised by an extensive use of renewable energy is the necessary large occupation of land, due to the usually very low density of the natural energy flows.

Trying to set ex-ante quantitative limits to the km² that renewable energy collection should not overcome is nevertheless meaningless, for at least two reasons: multi-utilisation of space (solar roofs on houses for instance), necessary differentiation in criteria according to the type of land (or sea) used (off-shore versus in-shore wind farms for instance).

Instead, we consider in VLEEM that priorities have to be set in the use of land in view of sustainability: first agriculture and food production, second urbanisation and transport, third forestry and natural space for human well-being and for biodiversity, and then industrial activities including energy. Space requirement for renewables on-shore should necessarily consider these priorities (including whenever relevant the multi-utilization of space).

Another sustainability problem is raised by renewables, in particular from an ethic viewpoint, if the development of renewables has hardly reversible consequences on land and human settlement. This is already the case with many hydroelectric installations, this might become the case with biomass (as regard future biodiversity) or solar electricity or wind power (because transmission lines).

Air pollutants issue

Periodically, global environmental problems emerging from the accumulation of local pollutants appear, and are more or less well resolved: HFC's and the ozone layer destruction, acid rains and the deperishment of forests in Canada, Scandinavia, Siberia,...More recently, the brown cloud covering for months the whole south and south-east Asia, from Pakistan to the Philippines and Irian Jaya raises fears about possible massive drawbacks on the health of billions of people.

The main difference with green houses gases or nuclear is that these unsustainable consequences are not intrinsically linked to the energy carriers which are produced and used, but on the technical conditions in which the production and use are done. Acid rains result from the SO₂ released by the fuel combustion, but it is absolutely possible to burn any fuel without releasing any SO₂. The same for NO_x, CO, etc...

Therefore, we can hardly consider that fossil fuels or biomass raise sustainability problems because of local pollutants which cannot be solved except by reducing the quantities. This is a matter of improving the technical specifications of the products and the techniques to produce and use these products. VLEEM will point out these necessary improvements, but will not set any sustainability criteria or indicator on this respect.

Other industrial risks issue

By other industrial risks related to energy activities, which raise question as regard sustainability, we understand: the pollution of the seas and oceans by hydrocarbons, threatening various life species among birds and water resources, and part of the alimentary chain; the depletion or poisoning of fossil natural water resources in relation to geological consequences of energy mining activities; the use and poisoning of surface water resources by energy production activities, creating a threat on water availability and aquatic life; etc...

Again, technical solutions to these risks do exist, and sustainability problems are created by the way energy is produced and used, not by the essence of the energy products themselves.

As for local pollutants, VLEEM will point out the problems and these necessary improvements on this respect, but will not set any sustainability criteria or indicator .

Natural resources issues

The availability of the resources is a fundamental stake of sustainability. The problems of the resources exhaustibility concerns, in particular, four resources.

- the impoverishment of the soil
- the biological diversity
- the fresh water availability
- the fossil fuels depletion

We concentrate in VLEEM on the problem of the depletion of fossil fuels, and more particularly oil and gas.

The eventual scarcity of fossil fuels energies and in particular of oil and gas is in the centre of an important debate around the “peak oil”. Even if all the specialists don’t agree with the exact date of the peak, all are sure that oil and gas production will peak before the turn of the century. This raises two major questions as regard sustainability: for our generation and the next ones, the peaking in hydrocarbons production may raise enormous socio-economic difficulties worldwide, and major international tensions; more distant future generations would not benefit at all of natural hydrocarbons.

The fundamental question raised by exhaustible resources as regard sustainability is whether or not the price of these resources and its evolution can reflect properly the two dimensions of the problem, production peaking for these generations, and availabilities for more distant future generations.

Various economic theories propose different views on this question, but all consider some form of adjustments on the market prices and the behaviours of the resources owners considering that the market can “solve” the problem, at least as regard production peaking. But the question remains whether the transition towards alternative energies could be progressive and “natural” or not. That is to say if oil and gas price signals will be high and

soon enough for alternatives to be ready earlier than the expected oil and gas production peaks; or if oil and gas production will start decline before, forcing consumers to fight for increasingly scarce resources and to adapt through crisis.

If depletion rates are supposed to be entirely determined by the price evolutions and expectations, can we assume that this would ensure the dynamic equilibrium of the market, and, moreover, can we assume that all owners of exhaustible resources will behave like that? Would some major oil producing countries (Saudi-Arabia, Iraq, Iran, etc...) behave differently and adopt a restrictive approach of the depletion (adapt the depletion rate to the needs of today, keep resources for future generations, etc...) , the peaks in production may happen even earlier than expected, shortening the delays for transition.

In the VLEEM project, we have assumed that geopolitical sustainability, as regard existing generations during the 21th century, implies a fair allocation in the distribution of these resources based on the relative needs of energy services at the end of the century.

1.1.2 How decision making can cope with sustainability, in particular for energy RTD strategies

VLEEM's ultimate objective is to provide information to the EC/DG-RTD for decisions regarding major RTD programs in the field of energy. These major energy RTD programs involve very long time spans, some of the expected industrial outcomes not likely to be ready before 60 to 70 years from today (fusion for example). The rationale behind these decisions is indeed to prepare alternatives to exhaustible fossil fuels likely to supply the energy needs that the development of the European economies will generate, but also likely to fulfill the more fundamental (though loosely defined) objectives of the EC as regard sustainability.

Therefore, there is a need to clarify how policy decisions, in particular in the field of RTD, actually account for sustainability, and which types of problems this raises. This clarification is necessary to give more chance to the prospective information delivered by VLEEM to really be useful for the EC/DG-RTD in its decision process.

Sustainable development may hurt

According to Brundland's report definition, sustainability is primarily a matter of "ethical" sharing of natural resources (in the broad sense) between today's and future generations. But refraining to use exhaustible resources and to modify the environmental conditions beyond what the market would indicate spontaneously suppose policy actions that may go against existing economic interest and individuals preferences (precisely expressed by the market). It may therefore result that targeting sustainability and trying to foster sustainable development would imply hard conflicts of economic and social natures.

In VLEEM, we assume that EC decision makers are fully aware of this question, and ready to tackle seriously these potential conflicts in order to make the necessary changes towards sustainability possible. In particular, we take for granted that there is no a-priori limitations on the prices of energy services which would appear necessary to foster sustainability in energy systems in the future, whatever the mechanisms through which these prices are built up, including taxation, whatever the mechanisms through which these prices are made accepted by the population and the economic actors, including radical changes in the overall fiscal structure, and whatever their consequences on the economic structures.

«Future generations? What about today's generations?»

Today's generation preferences are known. Those of future generations are not. Scientific evidence of some environmental problems over the very long term can still be questioned, but the negative economic and social short term impacts of some decisions towards sustainability are immediately experienced. In 100 years from now we will all be dead!

How to balance “hard” environmental criteria for the benefit of future generations with “hard” social and economic constraints for today's generation? This is the key question when trying to establish practical sustainability criteria. Here is the huge challenge for policy makers.

The VLEEM back-casting philosophy implies that precise quantitative criteria are set to define what sustainability of energy systems is, and what quantitative environmental conditions should be respected at the target year by the energy system and technologies (likely to result from EC energy RTD programs) to match the sustainability objectives of the EC. In order to fully account for the necessary trade-off between the severity of these environmental objectives and the severity of the economic and social conditions imposed on the population in between to fulfil these objectives, we have adopted a pragmatic approach, reflecting the conditions of this trade-off, rather than a pure normative definition of the criteria. Indeed, the ultimate purpose is to provide useful information to feed the debate on energy RTD decisions in regards to sustainability, not to impose a particular normative view of what sustainability is, and what it imposes on the energy scene.

Role of scenarios in sustainability discussions

Scenarios are the backbone of prospective studies. Scenarios intend to be consistent pictures – visions - of possible futures, and stories about how to reach this future.

Most of prospective studies consider a “Business As Usual” scenario, in particular to show how bad the situation would be if nothing is done to foster sustainability.

“BAU” scenarios, because they refer to well known evolutions and mechanisms, and because they have a perfume of forecast (if not prediction), are definitely appealing to decision makers. Of course, they are aware that the consequences of such an evolution are bad, that definitely “it is not possible”, but implicitly they believe that the problems will find their “natural” solutions through future technology development which are unpredictable today.

At the opposite, sustainability scenarios point out what has to be changed, in technology, behaviours, structures, to reach sustainability. Decision makers are therefore uncomfortable in two ways: change means uncertainty, change means risk (political, economic,...). Provoking the changes through decisions is politically risky on the short term, without guarantee that “it will work” on the long term.

VLEEM has not designed any “BAU” scenario, for the simple reason that such a scenario won't make any sense on a century time frame (nothing will be “as usual” on such a time frame). The question that VLEEM tries to resolve is not how any unsustainable possible future would look like, but how, with which technological development, with which circumstances, sustainability is likely to be reached in one century from now (or before). All VLEEM scenarios are sustainable scenarios.

Sustainable Development implies tough political decisions

Among the information and messages that will come out from VLEEM scenarios, two refer to very sensitive issues as regard political decisions:

- Irreversibility created by today's decisions
- The more radical the changes, the more time is needed

These issues are very sensitive because they impact the decision in the short term, although the negative or positive impacts will be visible only on the long to very long term. France has just taken decision about the development of the EPR nuclear reactor, but this decision will affect the nuclear R&D and future development over the next 50-60 years although sustainability criteria for nuclear have not yet been adopted. Benefiting of a trans-Europe high speed freight rail network in 2050 imposes that decisions are made within the next few years on huge infrastructures like Lyon-Turin, even if such an infrastructure is evaluated not cost effective today.

VLEEM is focussed first on major energy supply technologies likely to result from the main European energy RTD programs. In that respect, sustainability scenarios have to point out the irreversibility and the time frame involved by each main RTD programs and expected resulting technologies which may impact EC decisions in the short-medium term. Besides, VLEEM also reveals the context conditions for these technologies to fully contribute to sustainability, how these conditions are compatible with irreversibility created by current decisions in various fields as transport, urbanisation, grids, etc., and which time frame is involved for the conditions to be fulfilled in due time. We have to make sure that this additional crucial information is actually disseminated to the appropriate decision makers, and that feed-back to DG-RTD is properly organised.

1.2 Back from a sustainable energy world in 2100 to now

1.2.1 sustainability and back-casting

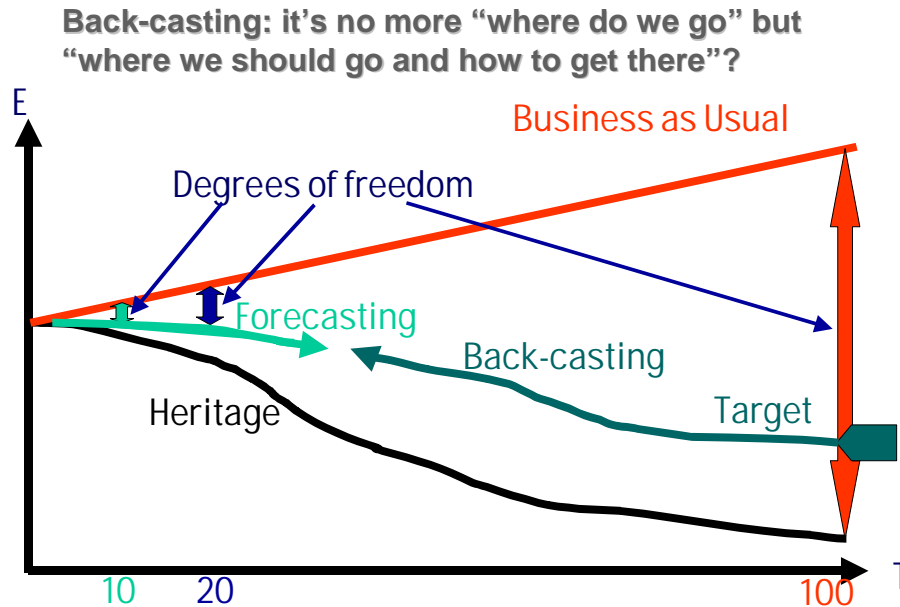
The back-casting approach is strongly connected with the concept of sustainable development or more generally with a concept of a desirable future. The whole task is to find trajectories able to convert the existing system into a desired future system.

In general terms, a back-casting approach involve three steps:

- first, design the desired future, in our case the sustainable energy systems according to the criteria reviewed above
- second, identify and assess the necessary changes as compared to the current situation to reach the desired future
- third, assess the problems and conditions to implement the change.

Then comes the question of political acceptance of the concept and methodology of back-casting, which is a pre-requisite to link the results of the VLEEM study to decision making in the R&D field, which is the ultimate objective of the project. This raises very similar questions as those addressed above (& 1.1.2).

In VLEEM, only the technology and the organisation of the energy system (including end-use of energy) are supposed to enter in the field of the debates and decisions about sustainability, not the population growth or the people's life styles and behaviours. Therefore, backcasting is only strictly applied to the whole chain from the primary energy carriers down to the energy services, the later being taken for granted. The needs of energy services are still assessed with a forecasting philosophy, through general but simple causal relations with demography, wealth and life styles.



1.2.2 Building up visions at 2100, 2050

Projecting the social and economic context

One of the fundamental driver of the social and economic context considered in VLEEM is the demography: population, age pyramids, urbanization, household structure, etc... Fertility, which drives the demography is indeed a matter of woman emancipation, which goes along with economic development, human rights and democracy. All visions built in VLEEM up to 2100 consider this movement towards woman emancipation as a key component of any future social development in which it make sense to investigate sustainable energy systems over the very long term. This movement can be faster or slower depending on the world region and the scenarios, but it is considered unavoidable. One of the consequence of this basic assumption is that, sooner or later, the world population will peak and then stabilize or even decrease. Three "visions" have been elaborated accordingly.

In VLEEM, the economic development is driven by the human factor, considered as a combination of labor force, time allocated to work and information embodied in skills, organisation and capital. Demography indeed drives the labor force, but social preferences and cultural values which determine the use of time (during the day, the week, the month, the year, the life) also drive both the labor force (through the ages when people leave the education system and when they retire) and the time spent at work. In that respect, there are

interferences between the forces behind the woman emancipation and those behind the human factor, which have to be accounted for in the three visions mentioned above.

In addition, the information embodied in skills, organization and capital is captured in VLEEM as the cumulative result of the evolution of the education system. Since education is also a matter of economic development, human rights and democracy, it goes along very much with woman emancipation, and therefore with demography and labor force. Also, the longer the time spent in the education system, the shorter the time spent at work in one's life. Again, the forces behind the information embodied in skills, organization and capital strongly interferes with those behind woman emancipation and the time used for work, within the human factor. All these forces are to be accounted for consistently within the visions.

The socio-economic projections which result from the mechanisms shortly presented above correspond to the "potential" socio-economic development likely to derive from the fundamental drivers of the demography. In one sense, this is strictly compatible with the economic and social dimensions of sustainability considered in this study: these projections do indicate to some extent the maximum needs of energy services that the energy system may have to fulfill in 50, 100 years from now, while matching environmental sustainability criteria, according to the demographic visions.

Is such a position sound and realistic? Can we consider that the physical capital can be actually accumulated in such a way that it allows the human capital to produce the maximum it can within the frontiers of the education – information and the time budget allocation? This is in fact a matter of savings pattern, business opportunities and fluidity of the financial flows across the world. Certainly, one can consider that both economic and social sustainability considerations, and economic globalization, impose business opportunities to be more equally spread all over the world, and financial flows to circulate more freely everywhere. Nevertheless, it is still unclear whether or not the global balance of the savings with the necessary accumulation of physical capital worldwide could be jeopardize by the evolution of the savings pattern, in relation with the demographic transition and the average aging of the world population. This question has been addressed recently by the IMF(International Monetary Fund), and the answer still depends on the theoretical appraisal of the savings pattern. Up till now, we have adopted in VLEEM an optimistic view based on the theoretical ground of the model INGENUE of the CEPII (used by the IMF in its recent study), according to which households have a saving behaviour across their life which maximizes their overall consumption during their life. This view is optimistic since its result is that the savings pattern do not constitute an obstacle to realize the potential economic production as projected by VLEEM (in other words, the physical capital accumulation can be consistent with the potential growth).

Projecting the needs of energy services

Energy services must be understood in their "vleem" meaning, i.e. in relation with basic life and production functions: providing mobility, food conservation, high exergy processing,...

The needs of energy services are projected

- for the main four socio-cultural functions considered in VLEEM:
 - o food and feeding
 - o shelter and lodging
 - o self-accomplishment
 - o mobility
 - o economic production

- for three socio-spatial zones: urban, rural, sub-urban.

The projections are displayed in matrices crossing:

- quality standards for the energy services: low energy, medium energy, high stationary energy and high mobile energy
- density and spatial dispersion of energy services: low versus high density; low, medium, high, unit power

The method used to project the needs of energy services consists in three steps:

- allocate the needs of energy services among 8 cohorts of households, defined by the age of the head of the household and the size/type of household;
- within each cohort, relate the needs of energy services to three fundamental drivers within a global model: the time used in the socio-cultural function, the affluence of the household and the information level of the economic system;
- aggregate the results through the cohorts, the zones, the functions to produce a global matrix of needs of energy services expressed with a single standard measuring unit.

Projecting the useful energy requirement

Projecting the useful energy requirement is essentially a matter of assessing the technology options available for fulfilling the needs of energy services and deciding the appropriate technology option depending on the socio-economic context in the one side, of the overall energy technology paradigm in the other side.

Projecting the needs of energy services is done still within an usual forecasting or exploratory approach. Projecting the useful energy requirement is already within the back-casting approach: indeed the decision on what technology option is or not appropriate to address such or such energy service must refer to some explicit criteria, among which necessarily those considered for sustainability. For example, the issue of the resource constraints will not be the same in the various possible technology paradigms over the next century, and will have different implications on requirement for end-use efficiencies of the technology options.

The main difficulty in “converting” the needs of energy services in useful energy to be supplied by the energy system is that we are just unable to describe and to specify in details the technology options which may be available in one century from now. The approach which has been implemented in VLEEM to overcome this difficulty is that of step changes in efficiency levels for the various energy services. Four steps have been identified: current technologies, best (most efficient) alternative known and experimented, best (most efficient) alternative under investigation (R&D, demonstration,...), thermodynamic limit.

The projections are expressed in

- distribution of the energy services among the four generic technology options
- specification of the technology options in useful energy (MJ) per unit of energy service

Building the energy visions corresponding to the technology paradigms

The last step is to build up regional and world energy balances for the technology paradigm considered to be dominant at 2050, 2100.

This final construction consists “simply” in allocating an “optimal” mix of energy chains (from primary resource to useful energy) for all useful energy requirement, all technology options, all energy services.

The concept of optimality refers here first to sustainability criteria. Then it can consider additional criteria among which the level of uncertainty regarding the availability at that time, the cost, the social and political acceptability, etc...

These energy vision do describe a state of the energy system in 2050, 2100 which can fulfill all the needs of energy services which could be generated at that time by a sustainable world, from the economic and social sense, and at the same time respect the environment sustainability criteria.

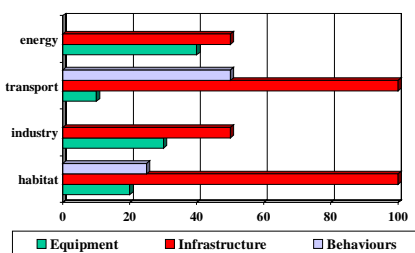
1.2.3 Building up trajectories back from the visions to nowadays

Accounting for technology diffusion

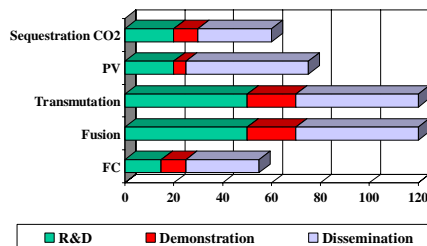
The energy visions provide a description of possible combinations of technologies likely to fulfill the sustainability criteria in a dominant technology paradigm at a target year. According to the technologies and to their context, the diffusion path can be shorter or longer: it depends on the life time of the technology in place to be substituted, on the expansion of the market for the competing technologies, of the resistance of the technologies in place in the renewal or expansion. It could take 10 years before a new technology takes 100% of sales of new cars, and 25 to 30 years before it takes 100% of the total stock. In the case of power plant, where the life expectancy is 4 to 5 times that of cars, the diffusion path of a new technology is much slower, and it can take up to 60 to 70 years before a new technology takes 100% of the plants (of one particular category).

Accounting properly for these diffusion curves provide reliable information on when a technology should start to penetrate the market in order to be developed as much as shown by the energy vision at the target year.

At the heart of back-casting: heritage constraints and temporalities of changes to reach the target



Temporalities and change of technology paradigm : a central axis of VLEEM



Accounting for temporalities to prepare technology diffusion

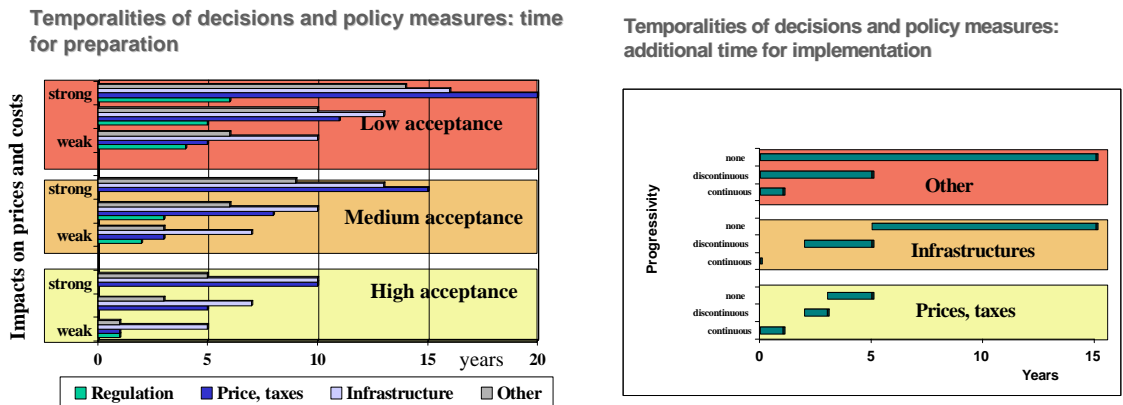
Saying that a technology starts penetrating the market means that all economic, political, institutional and social conditions are fulfilled for the technology to be accepted by the consumers and attractive to them.

It is very doubtful that such conditions could be “naturally” fulfilled, or result from a simple market mechanism, in particular when the technologies participate to a different paradigm as compared to that in place.

A package of policies and measures, involving public and private stakeholders, is necessary to create these conditions in most cases. These policies and measures involve also temporalities which precede those of the deployment of the technologies: R&D programmes, financial incentives, support to prototype investments, etc...

A sound accounting of these temporalities is necessary to identify when the decisions should be made to launch the overall process leading to the market penetration of a technology. Depending on the scientific background of the technology, of its cost components, of its technical problems, of its infrastructure requirements, the delays before the technology could start penetrating the market could take up to 50 to 70 years (case of fusion or transmutation for instance).

Therefore, it is absolutely necessary to confront these delays with the time available between today and the date for the necessary start of the market penetration of the technology compatible with the energy vision. A target year for sustainability not far enough would therefore prohibit several technology options to materialize in due time.



Accounting for milestones and conditions

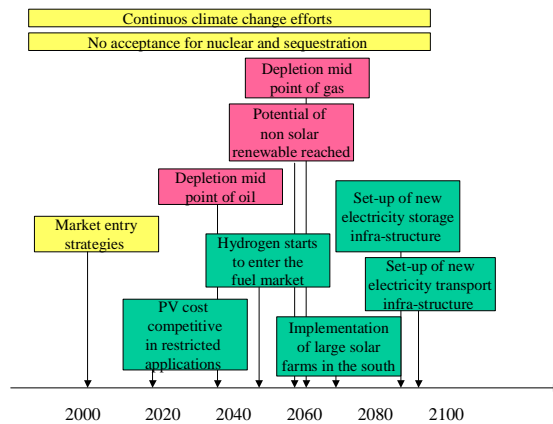
The analysis of the trajectories necessary to reach the end-point and the associated temporalities clearly indicate when each step involved in the decision process leading to the development of new technologies and the elaboration and diffusion of these technologies should be reached, and which and when necessary economic and social conditions should be fulfilled.

This analytical process result in the identification of the main milestones of the trajectories and the meaning of these milestones as regard:

- the required scientific knowledge to be acquired preliminary to the technological development, through basic R&D

- the solutions to the technical problems to be overcome before the technology can be widely disseminated, through applied R,D&D

Example of milestones and prerequisites for solar



- the economic conditions to be created before the technology can compete effectively with existing ones or other new alternatives, through industrialization process
- the social and policy conditions to be installed before the technology can be widely accepted by all stakeholders and the public.

Accounting for interactions, exclusions, synergies in technology paradigm construction

The history of technologies shows that the construction of the technology paradigms – as the coal / steam machine in the 19th century or the oil / internal combustion engine in the 20th century – proceeds as the result of synergies, interactions and exclusions among competing technologies. This is well illustrated by the oil history: oil has first developed on strong synergies with ICE which has excluded the steam machine from the road transport ; interactions among oil products in the refining process has permitted to oil to compete with coal –and finally win almost everywhere – in the heavy thermal end-uses, etc...

In its attempt to build consistent images of possible sustainable energy systems in 2100 and trajectories to reach them, VLEEM tries to account as much as possible for these synergies, interactions and exclusions in the construction of the technology paradigms corresponding to the various case studies. This is primarily focused on the synergies with technologies at the end-use level and among primary energy sources, interactions with the energy efficiency technology concepts, energy carriers and network concept, exclusions among primary energy sources.

Building up the road maps for technology paradigms construction

Road maps are understood in VLEEM as synthesis of all the above elements in graphic visualizations of the distribution across time of all the events which constitute the back-bone of the trajectories.

The example displayed below emphasizes partially the nuclear road map corresponding to the development of a nuclear paradigm in Europe (only the development of the nuclear technologies are shown on this partial road map).

population around 8 billions at that time. After that, the trend towards a decreasing fertility rate continues in developing countries, and nativity policies, if any, fail to convince women to get more children almost everywhere. This scenario means that individual values take the lead over collective values.

In order to describe the content and logic of these three scenarios, available material and elements from various prospective studies have been used whenever relevant, in particular Shell ("People and connections, global scenarios to 2020") and IPCC (SRES).

Life-styles, social link

High Pop	Mid Pop	Low Pop
<p>Convergence of life styles of the “elites” of the production system throughout the industrialised and industrialising world (US model?);</p> <p>Growing economic discrepancies between these people and the common people everywhere; growing weakness of the social link and growing social unrest.</p> <p>The traditional life styles give up only very slowly in the developing world; social problems are solved through emigration.</p> <p>The depopulation of rural areas and the growth of urbanised areas do cause shifts in life style and cultural patterns. Access to "modern" infrastructure and communication technologies facilitates access to minds of people and creates technological frog-leaps (e.g. like cell phones in the developing world nowadays) on the one hand, but do also create at the same time a global and levelling view on cultural and social values (TV, internet,, "hamburger and cola culture") and an extremisation of cultural and traditional identities..</p> <p>The share of aged people (65+) is growing considerable (9% 21%), especially in the developing world (tripling by 2100, 7% 20% and even 22% in rural areas), creating a global need for extensive health services and facilities, growing urbanisation and concentration makes them however more efficient and accessible.</p>	<p>Strengthening of specific regional modern life styles, according to regional “elites” life styles.</p> <p>The regional elites profit from an increased communication and global availability of novelties, services and goods.</p> <p>Social discrepancies are mostly solved through transfers and redistribution mechanisms, both within regions as interregional.</p> <p>The lower population growth, especially in the industrialised world and Asia, and aging effects cause a larger share of elderly person in the population (9 26%), however the share of 20-65 years olds remain more or less constant (47-50%).</p>	<p>Convergence of life styles of the “elites” of the production system throughout the whole world up to 2050. Growing economic discrepancies between these people and the common people everywhere; growing weakness of the social link and growing social unrest.</p> <p>After 2050, regional adaptation to the regional problems resulting from the general population decline and aging (15 36% in the developed world; 7 33% for the developing world). This scenarios has the largest share of elderly people, but the same time the higher share of potential economic active persons. This unbalance creates the most heavy burden on public funds to secure adequate health services.</p>

Potential economic development

High Pop	Mid Pop	Low Pop
<p><i>Industrialised and industrialising countries:</i> High population results in high active population, i.e. high potential labour. High and homogenous education in each region results in a high information level and high labour productivity; retirement and working hours strongly influenced by “struggle for job (life)”</p> <p><i>Developing countries :</i> major cultural and religious resistance to education and labour of women; the active population do not rise as fast as total population; average and education information level and labour productivity rise slowly; both put a high burden on the potential economic development, together with a vast and fast growing number of elderly people who do not participate in economic life themselves but on a positive side who are responsible for a parallel growth of the service sectors.</p> <p>Depopulation (urban pull) and aging in rural areas causes abandonment and less care taking for elderly people and a welfare loss.</p> <p>Public budgets and pension funds are heavily under pressure because of the unequal participation in labour by women and the growing amount of pensioners.</p>	<p>Active population development only constrained by demography; education and information level progress well everywhere and quality converges to a high global level; retirement and working hours reflecting cultural values specific to each region.</p> <p>The aging and population decline puts a heavy burden on public funds, nevertheless private initiatives to support pension and health service flourish, allowing governments to use revenues for other purposes, like R&D or education.</p>	<p>Active population development only constrained by demography; education and information level progress well everywhere up to 2050. Retirement and working hours strongly influenced by “struggle for life” everywhere after 2050, the social system becomes very hard to maintain if the same labour conditions as in the HighPop or Midpop scenarios, a longer working life time (65 70) is very probably.</p>

Actual economic development

High Pop	Mid Pop	Low Pop
<p><i>Industrialised and industrializing countries:</i></p> <ul style="list-style-type: none"> - no particular constraints on investment side, neither economic nor financial - possible social unrest due to high growing inequalities between the available career/job opportunities for business class and for common people. <p><i>Developing countries:</i></p> <ul style="list-style-type: none"> - possible financial constraint on investments due to unstable political situation and high risk for foreign investors; - economic unbalances due to high population 	<p><i>All:</i></p> <ul style="list-style-type: none"> - no particular constraint from the investment side, neither economic nor financial - social and political climate favourable for foreign investors in all regions without severe barriers. <p><i>Industrialising, developing countries:</i> time needed to build up the necessary infrastructures; investment trade-off infrastructures-production.</p>	<p><i>All, up to 2050:</i></p> <p>no particular constraint from the investment side, neither economic nor financial</p> <p>political climate favourable for foreign investors in all regions, although social unrest may be a handicap.</p> <p>Industrialising, developing countries: time needed to build up the necessary infrastructures; trade-off infrastructures-production in investment</p> <p><i>All, after 2050:</i></p> <p>Increasing economic and financial burden resulting from aging population and leading to more and more severe economic unbalances</p>

Capital flows

<p>Deruralisation and the fact that active population shares do shift only a couple of percent points create :</p> <ul style="list-style-type: none"> * a potentially large capital availability in the developed world, which is however used to satisfy the increased service needs and not so much as innovative capital for the industry; * in the developing world most of the capital is generated in urban areas where it is used in the intensive and concentrated needs (infrastructure (industry) and service). 	<p>The share of potential economic active people is somewhat higher than in HighPop, generating a higher cash flow and creating a higher and more balanced welfare level. The depopulation of rural areas however continues, higher in the developed world (halves) than in the developing world (-1/4). The fact that the developed world's population decreases more is however a brake on a continuous high development, the developing world can take over partially the economic drive.</p>	<p>As Midpop to 2050, afterwards, welfare decreases due to the aging and declining population. Capital flow or savings are very low, emphasis is given to securing (health and social) services dealing with the population mix.</p>
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Migration pattern

High Pop	Mid Pop	Low Pop
<p><i>Economic Pull:</i></p> <ul style="list-style-type: none"> - within industrialised and industrialising world, discrepancies in affluence increase, calling for increased migration movement - from developing to industrialised and industrialising world, attraction of high education people by high salaries -within developing world incentives to migrations <p><i>Social/political push:</i></p> <ul style="list-style-type: none"> - within industrialised and industrialising world, few pressure to migrate - from developing to industrialised and industrialising world, and within the developing world, social/political pressure force people to migrate, but not highly educated immigrants are not welcome 	<p><i>Economic Pull:</i></p> <ul style="list-style-type: none"> -substantial improvement of living conditions everywhere progressively decrease the search for “eldorados” <p><i>Social/political push:</i></p> <ul style="list-style-type: none"> - more quiet world, less social/political pressure forcing people to migrate 	<p><i>Economic Pull:</i></p> <ul style="list-style-type: none"> -substantial improvement of living conditions everywhere progressively decrease the search for “eldorados” up to 2050; afterwards economic conditions deteriorate unequally throughout the world, creating new migration movements <p><i>Social/political push:</i></p> <ul style="list-style-type: none"> - more quiet world, less social/political pressure forcing people to migrate - active immigrants are more and more welcome as population is aging

Land use changes -agricultural policies

<p>With substantial food requirements for the continuous population growth, there is large pressure and demand for ongoing R&D and innovation in agricultural techniques in order keeping on improving production efficiency and food quality; the developed world experiences an increasing urbanisation putting more pressure on land area for other uses (mobility, recreation, nature) and at the same time is concerned about environmental impacts (high pressure leads to unwanted and damaging effects);</p> <p>The developing world has less interest in conserving the environment because pressure for food is overwhelming and improvement in agricultural techniques is slow; also a high number of large metropolises emerge, and degradation of rural land continues with decreasing yields.</p> <p>Scarcity in sweet water increases dramatically in the developing world, due to increasing needs and bad management techniques</p>	<p>The initial population growth pattern, equal to HighPop, and the slow starting shift from rural to urbanised areas, requires a very efficient food system. Agriculture is highly intensified, mechanised and technologised everywhere, resulting in higher efficiencies in production and less sweet water needs.</p> <p>The lower population growth in the second half of the century, puts less pressure on land and all activities related to land use get balanced.</p>	<p>Trends are similar to mid-pop until 2050. The declining population after 2050 can satisfactory depend on the already occurred changes and let more space available for other end-uses of land.</p>
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Resource availability

High Pop	Mid Pop	Low Pop
<p><i>Medium availability</i> the drive from the developed world to fuel its economy results in successful resource development, both conventional (ultra deep sea oil and gas , ...) as unconventional (nuclear, fusion, renewables) within industrialised/industrialising regions; elsewhere, the resistance and risks for foreign investment slows down the process of resources development ; the developing world remains mainly with its domestic ready available resources and hardly profits from the new resources' development.</p>	<p><i>High availability</i> the progressive disappearance of barriers to trade and financial flows among regions allows for a rapid expansion of existing resources all over the world, allowing access for all at market prices. Further development and exploitation of resources is mainly market driven and international ventures ensure the necessary infrastructure investments.</p>	<p><i>Medium availability</i> same as in mid-pop</p>

Resource distribution

<p>Security of supply is a master word in the industrialised/industrialising regions; this means supply diversification strategies (origins and fuels) and limited endogenous production; Developing countries have a restrictive export policy of natural resources, for cultural/political reasons mainly</p>	<p>Resources become a globalised market good, owned by private companies which have a wide portfolio of possibilities to offer on the market; it remains a "demand" market, with probably some commodity price level setting by the authorities in order to equalise energy cost over the consumers.</p>	<p>same as in mid-pop</p>
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Transfer and deployment of technologies

High Pop	Mid Pop	Low Pop
<p>The demand for tailor made products and services is high, including cheap standard of-the shelf solutions at low cost as well as very specialised ones, which are tailored to the needs of small groups of customers who are willing to pay more for a guaranteed service. The "mass market" solutions are abundantly available at low costs, especially in urbanised areas (global) and certainly in the developed world. Strong competition between providers may keep prices down. Historic dynamics do continue in technology change.</p> <p>Manufacturing is built upon regional resources and needs, leading to a high variation on the supply side.</p> <p>The danger from technologies as perceived by the public is not the same as the actual danger. this puts a high pressure on technologies which bear the risk of major disasters (e.g. nuclear, large infrastructures (pipelines, tankers)).</p>	<p>In order to minimise risk for the environment (and to be able to react reasonably quickly to new findings and developments), there are no big monoculture of technologies, diversification is the main policy of companies. In transition periods, technologies and energy carriers which may not be strictly renewable or environmental neutral, but with a low impact on the environment, appear.</p> <p>Demand and supply are well balanced and access to technology is easy and widespread, but technologies with negative environmental effects have little market potential.</p>	<p>The high rise in the first half drives technology development and transfer, large monotecnologies appear at low cost availability. Innovation is rather limited, performance and efficiency are the key topics. The population drive does contribute to continuous technology development, but once the trend has turned, further development slows down and only very specific regional applications for local needs emerge.</p>

Renewables

<p>Rural and developing communities that were willing to support the installation of small scale renewables, reject large scale options. Logistics, space constraints and environmental concerns prevent large-scale developments. Approval becomes more and more difficult. The oil and gas peak will trigger a further increase of biomass based fuel systems, based on the modification at low cost of the existing infrastructures. However biomass remains limited due to the severe competition regarding land availability with food requirements</p>	<p>Better land management, technological innovation and learning cause a beneficial situation for renewable technologies and potential deployment (except large hydro which is not accepted to increase out of environmental issues). The natural potential is used highly efficient and is distributed globally.</p>	<p>Initial high energy demand drives the development of all possible energy technologies. However global learning, diffusion and spill-over are limited resulting in more fragmented regional developments, which still are (highly) efficient and adapted for local climate mitigation issues</p>
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1.3.2 Three cases for three sustainable energy futures based on three different technology paradigms

Three sustainable energy systems in 2100 have been investigated and quantified for the Mid-Pop scenario.

The first case investigates a sustainable energy system in 2100 in which the existing technology paradigm based on fossil fuels is assumed to be still dominating. The growing hydrocarbons resource scarcity is assumed to be overcome by an increasing use of coal, directly and through conversion to electricity, gas (including H₂) and liquids. The climate change issue is assumed to be resolved through large extension of capture and sequestration of CO₂ at every concentrated end-use point (power plants, H₂ plants, energy intensive industries,...).

In the second case, nuclear energy is assumed to substitute first massively for fossil fuels in the electricity generation, then for direct use of fossil through hydrogen in the transport sector, and then in the other sectors. Capture and sequestration of CO₂ is assumed to be either unfeasible or not competitive on the requested magnitude and sustainability issues for nuclear are assumed to be solved over the century at acceptable cost conditions.

The third case investigates a sustainable energy system in 2100 in which capture-sequestration is assumed to be either unfeasible or not competitive on the requested magnitude, and sustainability issues for nuclear are assumed to be not solvable over the century at acceptable cost conditions. Only renewable energy, developed on a large scale, is assumed to be competitive to solve the climate problem over the century.

The three cases are based on some general principles which are exposed briefly below.

General principles for all cases

In all cases, we assume that sustainability as regard natural resources implies a fair allocation of natural resources among world regions, based on the needs of energy services of the regions at the end-point.

For uranium, this rule may change in non nuclear cases: the principle in these non-nuclear cases is to allocate uranium resources according to the nuclear heritage for base year.

In all cases, we assume that the resistance of oil to substitutes is dependant on the end-uses and the technical substitution possibilities in these end-uses according to our existing knowledge. There is therefore a hierarchy in the end-uses of oil/liquids, from the most difficult to substitute to the easiest one, as follows:

- kerosene for air transport
- bunkers for sea transport
- agriculture and fishing
- feedstocks and non energy uses
- remote industry (no gas network)
- remote small users (no gas network)
- road transport
- other thermal uses

General principles for the Fossil case

The generation of electricity and H₂ switches to coal+sequestration as soon as possible. In most cases this means a location of the plants along the costs and development of electricity/H₂ transport infrastructures on long distances.

Gas is used first for disseminates/low density end-uses where CO₂ capture/sequestration is not possible:

- road transport
- households
- small tertiary and industrial activities.

Nuclear is still used in some countries for base load (heritage): for Europe, this means 100 MWé installed in 2100, and 40% of world uranium resources used in Europe.

General principles for the Nuclear case

Two possible routes through which nuclear can become dominant:

- nuclear takes over coal because CO₂ capture/sequestration cannot be properly solved at the desired magnitude.
- nuclear takes over because the demand for H₂ from transport increases strongly and nuclear is better positioned to generate high H₂ quantities at reasonable cost without CO₂ emission.

The nuclear case is based on the assumption that the stock of long-lived radionucleides can be reduced substantially and that these and other sustainability issues will be solved at the end of the century, but not necessarily earlier. It is not based on the assumption that fusion has to become available and competitive soon enough before the end of the century.

Although a nuclear option, fusion is considered as a possible new route for elec/H₂ generation in all cases at the turn of the century, which may contribute to maintain sustainability beyond 2100.

General principles for the Renewable case

The renewable case assumes first that the substitution for hydrocarbons in land transport can be successful, through a combination of biofuels, electricity and hydrogen/fuel cells.

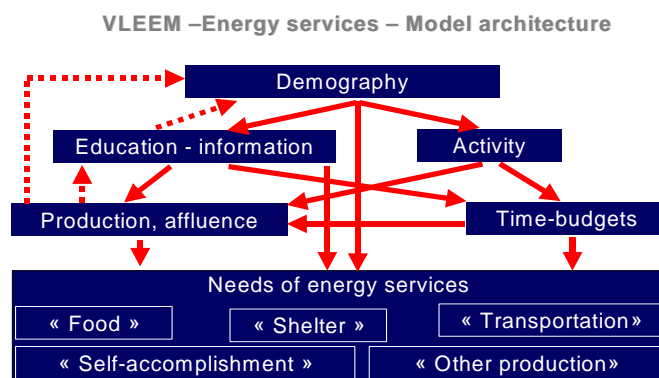
The generation of electricity and hydrogen without GHG emissions is assumed to be feasible by a combination of distributed generation in micro-grids using photovoltaics and biomass, and centralised networks linking remote concentrated production (wind, thermal solar) to consumers and micro-grids through long distance transport networks, including imports from other world regions.

In thermal end-uses, renewables are assumed to substitute directly for fossil fuels in low enthalpy energy services, and to substitute indirectly, through electricity and hydrogen, in other energy services.

2. Chapter 2: Energy Related Needs

The comprehensive description of the VLEEM sub-model dealing with the evolution of the needs of energy services up to 2100 (sub-model “BASES”) can be found in the annexes of final report of the first phase of the VLEEM project (VLEEM 1)².

The general structure of this sub-model “BASES” is as follows:



The model is run on ten world regions:

- Asia OECD Pacific
- China
- Europe
- Former USSR
- Latin America
- North Africa and Middle East
- North America
- Other Asia
- South Asia
- Sub Saharian Africa

For each region, the disaggregation is as follows:

population: urban, rural, sub-urban; 4 age classes

households: urban, rural, sub-urban; 4 size/composition classes

education: urban, rural; 3 levels

activity: urban, rural; 3 active population classes

time budgets: urban, rural; 5 socio-cultural functions

production: 3 socio-cultural functions plus one overall category

food: urban, rural, sub-urban, 4 ES³, for households; 7 ES for production

shelter: urban, rural, sub-urban, 4 ES, for households; 4 ES for production

self-accomplishment: urban, rural, sub-urban, 1 ES, for households

transport: 3 modes for pass, 3 modes for freight, 3 ES for production

other production: 4 ES

² See www.VLEEM.org

³ ES: Energy Service

We present below the main assumptions and results as regard the main drivers of the needs of energy services first, the results as regard the evolution of the needs of energy services up to 2100 second. All these assumptions and results refer to the Mid-Pop scenario.

2.1 The drivers of the needs of energy services over the very long term

2.1.1 Population

Population is the most fundamental driver of the needs of energy services over the very long term. It drives the number of persons and households who will express needs, and the information level of the society (through education) which determines the productivity and wealth, which in turn determines the magnitude of the individual needs and the production requirement.

Population growth

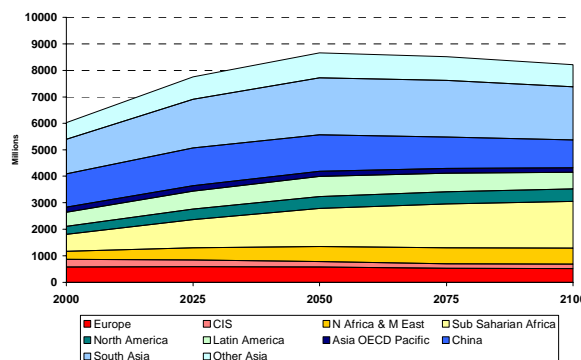
The Mid-Pop scenario is in line with the “Medium variant” of the United Nations projections until 2050 as regard fertility and mortality and depict a completion of the so-called “demographic transition” by 2050. It assumes a continuous decrease in mortality everywhere, a rebound of the fertility rates in the industrialised regions after 2050 up to 2.1 and a stop in the decrease of the fertility rate at around 2.1 in the developing regions after 2050.

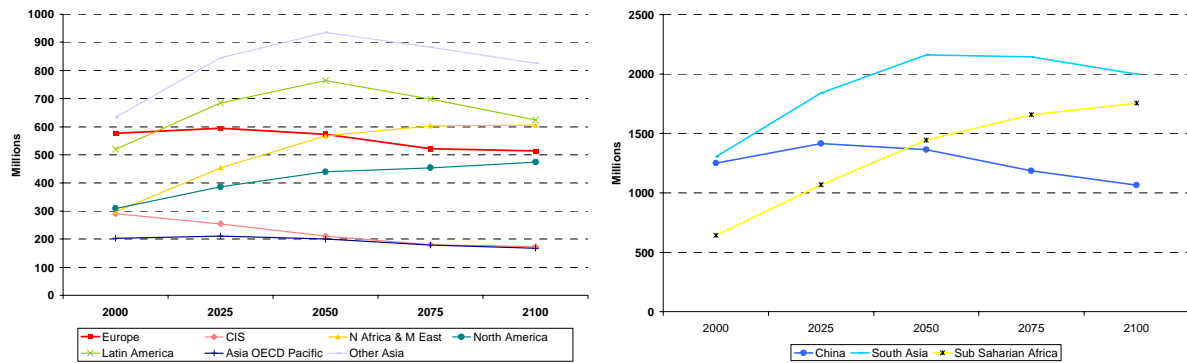
The world population is therefore expected to peak around 8.7 billion in 2050 and to slowly decrease afterwards down to 8.2 billion in 2100.

Sub-Saharan Africa is expected to experience the fastest population growth: its share in the world population would increase from 11% (2000) to 21% (2100). South Asia population is also expected to grow faster than the world population, its share increasing from 22% to 24%, whereas the share of Chinese population decrease from 21% to 13%, that of Europe from 10% to 6% and that of CIS from 5% to 2%. The shares of the other regions are expected to remain rather stable.

These population projections account for migrations of population among world regions, similarly to what the UN expect in the “Medium variant”.

Figure 1: Evolution and distribution of the world population by region



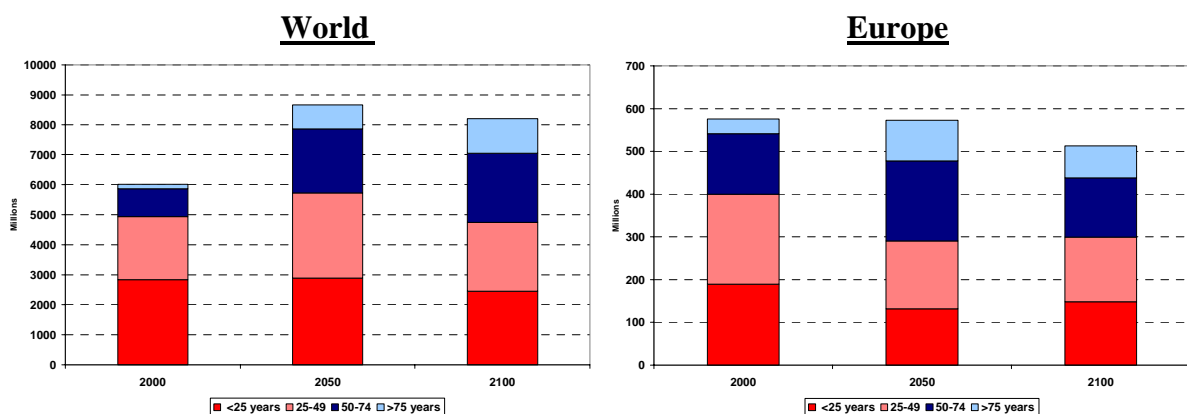


Population structure by age

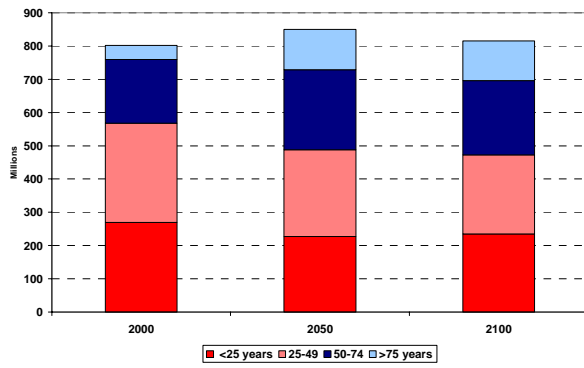
The age of the people is also a driver of their needs of energy services, because of its relation with the time-budgets (old people do not work any more for money) and with the health. This is why the needs of energy services are assessed within people cohorts in VLEEM-BASES, the cohorts being defined partly in relation to age. Behaviours and consumption patterns are assumed to change marginally with time within one particular cohort. But these behaviours and consumption pattern change drastically from one cohort to another, and therefore the change in the structure of the population according to the cohorts is likely to deeply affect the needs of energy services up to 2100.

In the Mid-Pop scenario, an important consequence of the demographic transition and of the reduced mortality is a considerable population ageing all over the world. The share of the world population older than 75 years increases from 2% in 2000 to 14% in 2100 and the share of those older than 50 years, from 18% to 42%. This phenomena is important in most developing countries and particularly in South Asia and China where the share of the people older than 50 years rises respectively from 18% to 43% and from 14% to 44%. In the industrialised countries, where the share of old people is already high in 2000, the phenomena is less pronounced : the proportion of the population older than 50 years would increase “only” from about 30% to 42% between 2000 and 2100.

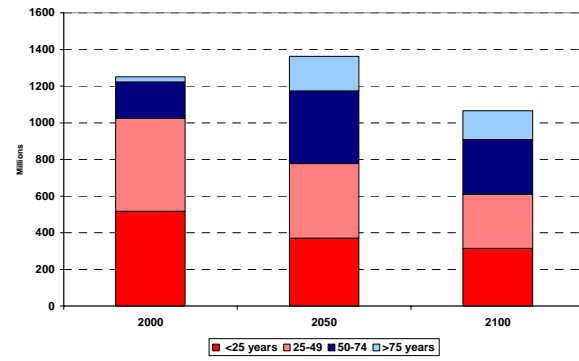
Figure 2: Distribution of the population by class of age



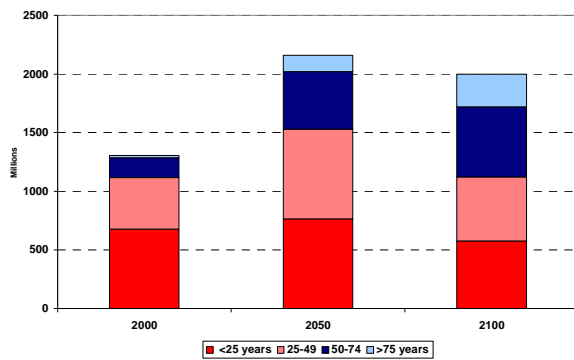
North America, CIS and OECD Asia



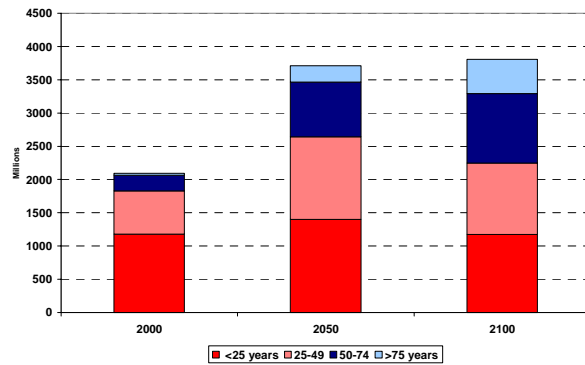
China



South Asia



Rest of the world



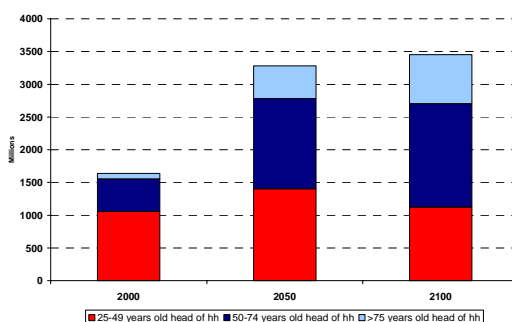
Households structure

Individual needs of energy services turn into different energy requirement according to the type and size of the household which hosts the person: the energy necessary to ensure a certain climate comfort in a house is roughly the same if there is two or three persons living in the house. There is some scale effect with the size of the households on the individual energy requirement corresponding to an energy service. In that respect, the structure of the households according to their size is also a driver of the needs of energy services that must be considered.

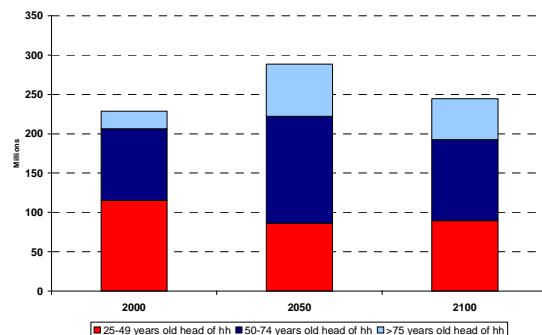
In the Mid-Pop scenario, in parallel to the population ageing, there is an ageing of the households, as expressed by the age of the head of the household. The share of world households with their head older than 75 years would increase from 5% in 2000 to 22% in 2100 and those with their head older than 50 years would increase from 30% to 46%.

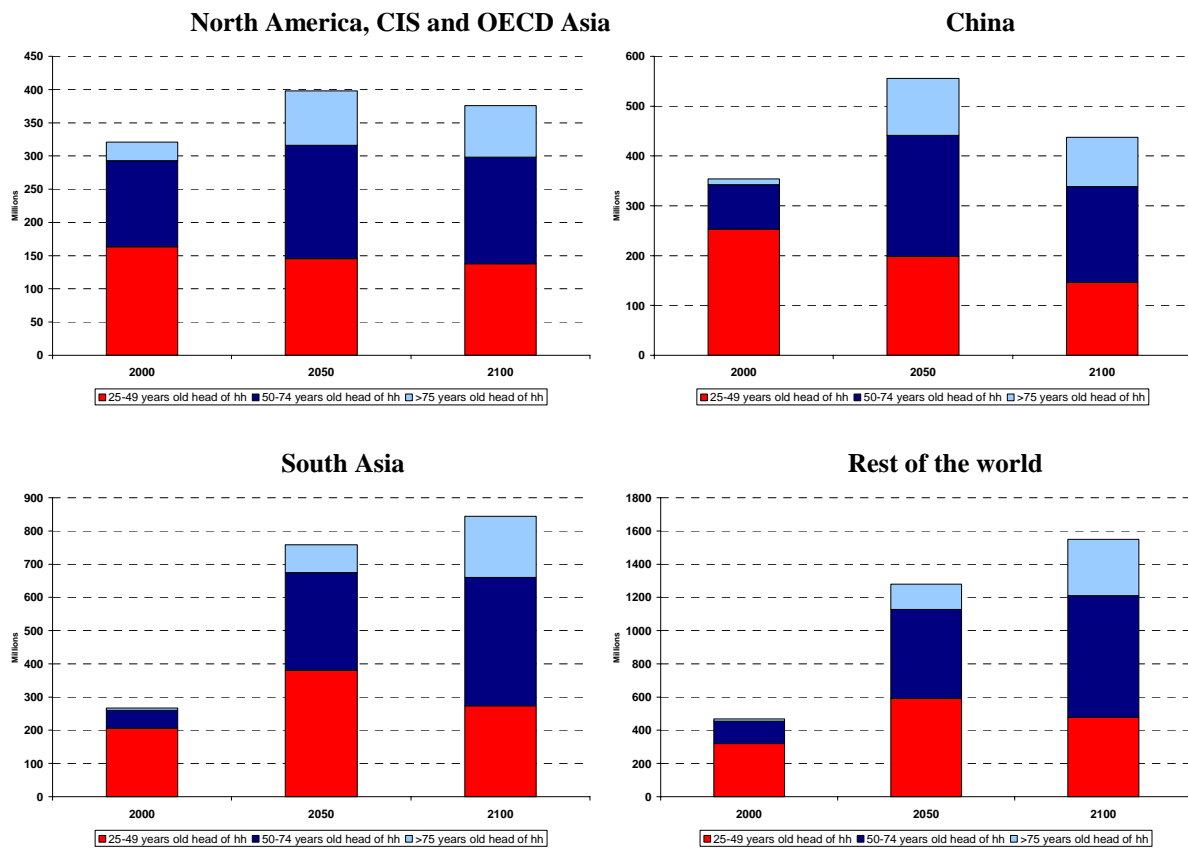
Figure 3: Distribution of the population according to age of head of household

World



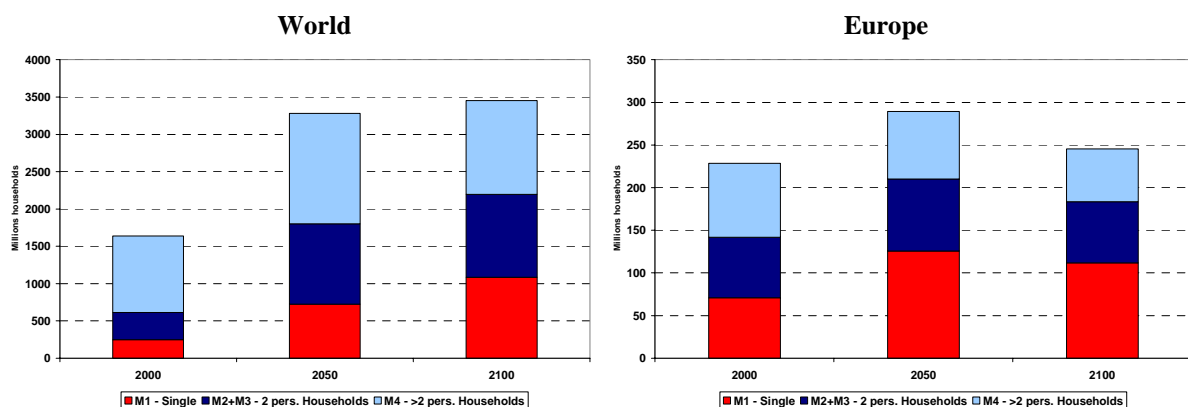
Europe

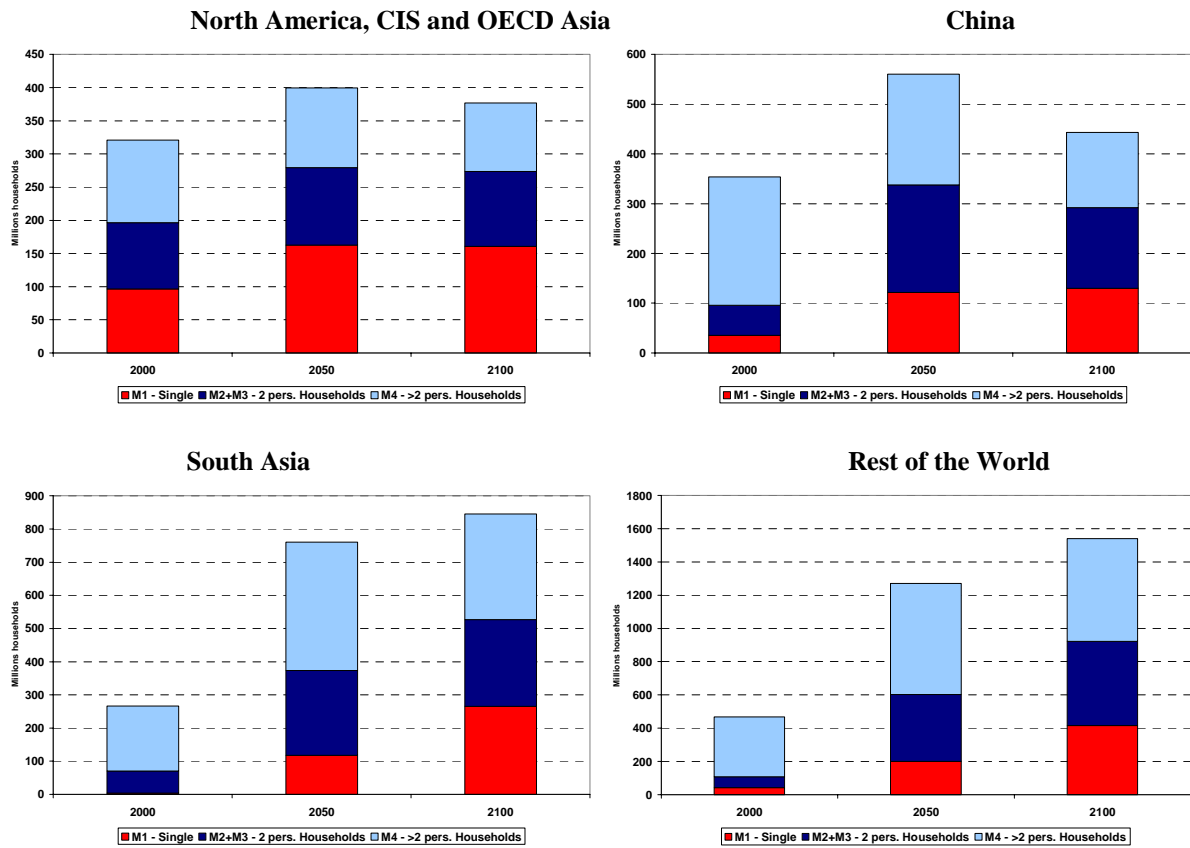




This change in the age structure of the households has a deep impact on the number, size and structure of the households. Most of the households in industrialised countries with a head older than 50 years are either one or two persons households. In developing countries, where a lot of households with heads over 50 years are still with large sizes, the same phenomena as observed in industrialised countries is expected to occur along with the demographic transition, the development of education and the release of housing constraints. In turn, the development of education and the release of housing constraints are also expected to boost the number of households with one person or monoparental households among the young people. Altogether, the proportion of households with one person is expected to increase from 15% to 31% between 2000 and 2100, and that of households with 2 persons from 22% to 32%. The share of households with more than two persons would consecutively decrease from 63% to 36% at the world level.

Figure 4: Distribution of the population according to the type of household

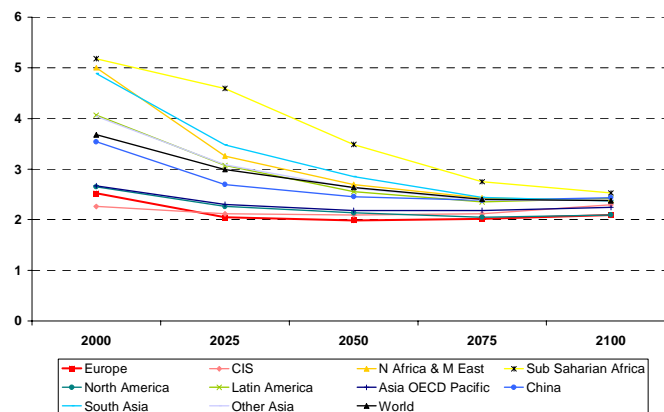




Average size of households

An overall consequence of the structural transformation of the households population, is an important decrease of the number of persons per household: expected from 3.7 to 2.4 persons per households in 2000 for the world. This important decrease is of the number of persons per households is expected to affect particularly Sub Saharian Africa (from 5.2 to 2.5), North Africa and Middle East (from 5 to 2.4) and South Asia (4.9 to 2.4).

Figure 5: Number of person per household (2000-2100)



Urbanisation

Energy consumption pattern are usually very different from urban to rural areas, in particular in developing countries: energy supply is much more available in urban areas, urban life-styles are much more energy consuming (i.e. daily mobility, comfort concept, household

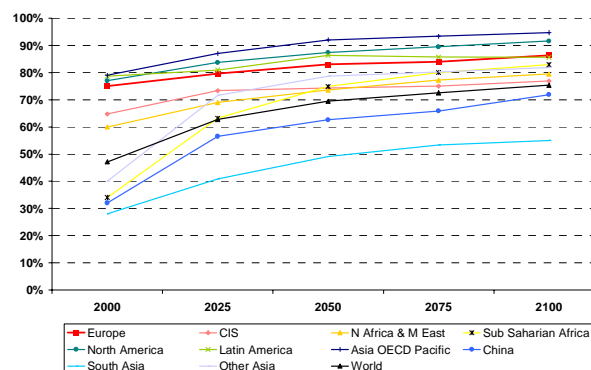
equipment availability, financial resources,...). An urban citizen can consume up to 10 times what consume a rural citizen, in average, in the same country. The same applies, but less pronounced, between urban and sub-urban areas in developing countries: behaviours and consumption pattern of people migrating from the countryside to the city, or from abroad, differ also significantly from those of urban people.

Energy supply issues are also very different in rural and urban areas, because of the much lower spatial density of the energy consumption in rural areas: this affect deeply the cost effectiveness of distribution networks, as electricity or gas today, hydrogen to-morrow.

Therefore, the distribution of the population among urban, sub-urban and rural areas is also to be considered as an important driver of the needs of energy services.

In the Mid-Pop scenario, along with the increase in the world population, a strong movement from rural to urban areas is expected. This movement is considered as a direct consequence of the physical limitation and the reduction of the population which can live in the rural areas, because of the limitation of the agriculture land first, because of the industrialisation of the agriculture second (less and less people can work and be accommodated per km² of agriculture land). This global phenomena is expected to result in an increase of the urbanisation rate in the world from 47% in 2000 to 75% in 2100, with the most drastic evolutions in Sub-Saharan Africa, China and Other Asia.

Figure 6: Urbanisation rate (2000-2100)



2.1.2 Education, Information and activity

Information is the second key driver of the needs of energy services in VLEEM-BASES.

Information drives these needs through two basic processes:

it determines the wealth through labour productivity, which in turn determines the equipment and consumption pattern of individuals and households, and therefore all the needs of energy services of the economic system;

it also determines the technical specifications of goods and services consumed by individuals and by the production system, which in turn determine the needs of energy services.

Activity is related to information because of the time spent at school by youngsters before they look for paid jobs.

Education and information

The information level is captured with an indicator constructed on the basis of the enrolment ratios of the youngsters in primary, secondary and tertiary school⁴.

Enrolment ratios are strongly dependant on the wealth of the countries, for two reasons: the cost of education, either for the tax payer or for the families with children, is increasing with the level of education, and the ability for them to pay for education depends on the average affluence of the population;

the trade-off in the families between sending the children to school and using them for family labour or for paid labour depends on the affluence of the family (even in public system where education is paid by the tax payer)

Countries with the same overall wealth (GDP/cap) can nevertheless experience rather different levels of attendance to school according to education and cultural policies, in particular as regard gender equality.

In the Mid-Pop scenario, we assume a certain convergence in cultural values, which means that obstacles to education other than economic are progressively removed. Enrolment ratios become only determined by wealth, following what has been already experienced in industrialised countries. Therefore, the situation resulting in 2100 from the world economic development⁵ is as follows: 100% of the 0-25 years have been enrolled in primary and secondary school in all world regions; enrolment ratios in tertiary education range from about 70% for the industrialised countries of today (with a peak to 80% in North America), to about 50% for the other regions, with Sub-Saharan Africa with only 42%.

Figure 7: Enrolment of the 0-25 in primary school, 2000, 2100

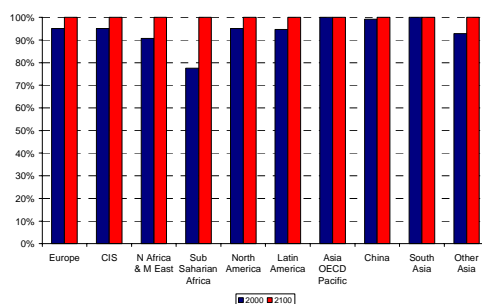


Figure 8: Enrolment of the 0-25 in secondary school in 2000 and 2100

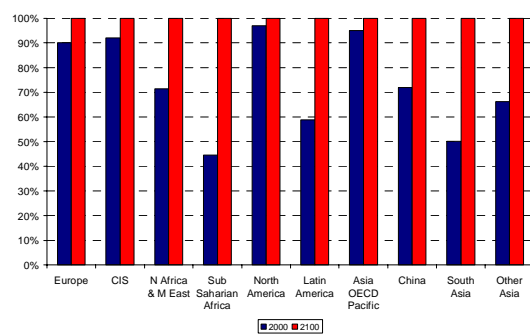
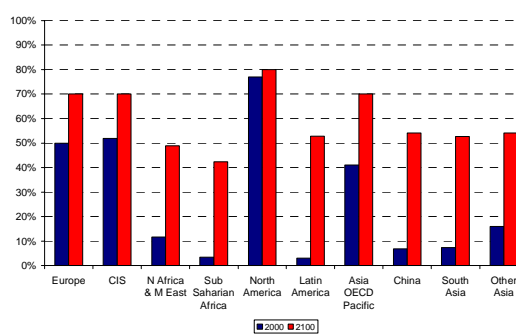


Figure 9: Enrolment of the 0-25 in tertiary school (2000, 2100)



⁴ for further information, see final report VLEEM 1, annex 1, in www.VLEEM.org

⁵ The world economic development is not assumed, but result from several forces, among which information (i.e. education in the past).

Information and productivity

The range of information levels across the world in 2000 is between 1.5 and 3 (level 1 corresponds to a hypothetical situation where 100% of the population goes to primary school, but where secondary and tertiary education do not exist; the maximum is level 6, it corresponds to a situation where 100% of the children are educated up to the tertiary level).

In the Mid-Pop scenario, the progress of education results in a steady increase of the information level everywhere on the world. The industrialised countries of today, which have higher information index in 2000, still have higher information in 2100. The range of the information level in the world in 2100 is between 3 and 5.

As shown by former econometric analysis (see VLEEM 1 final report, annex 1, in www.VLEEM.org), information level as calculated in VLEEM is strongly correlated to labour productivity (expressed by GDP per working hour). Two major interpretations can be drawn from the historical correlations:

- a geometric progression of the labour productivity with the information level on a very long time period (interpretation based on the assumptions that cross-country analysis can substitute for unavailable very long term time series);
- a logistic progression (S curve) , where the elasticity of the labour productivity declines with the progression of the information level (interpretation suggested by the historical analysis of the last 20 years in industrialised countries).

The apparent contradiction between these two interpretations could be solved with the help of the Kondratieff Cycles (related to major technology innovations every 25-50 years): the very long term geometric progression would appear as the overall envelope of shorter term S curves, each major technology step bringing the productivity on a new track.

In the Mid-Pop scenario, we have assumed that a certain convergence in affluence will occur across the world. For this reason, and to remain consistent with existing very long term economic growth assumptions (in particular those of the IPCC), we have decided to base our simulations on the second interpretation (S curve), and to forget about the possible consequences of new Kondratieff Cycles in the next 100 years on productivity in the most advanced countries.

Figure 10: Evolution of the information index (2000-2100)

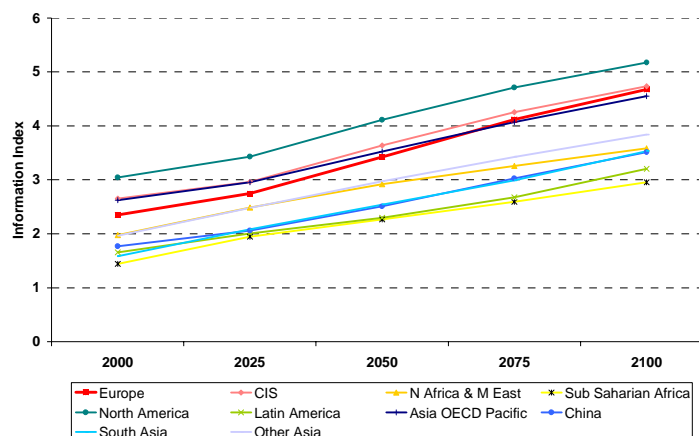
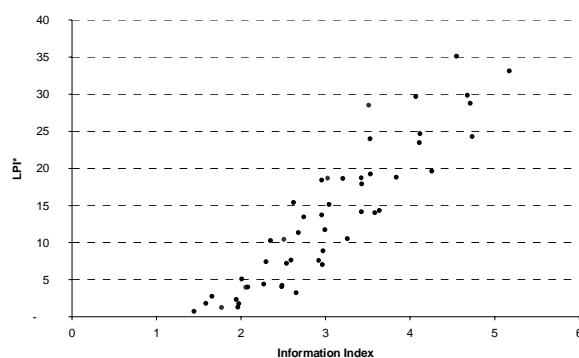


Figure 11: Labour productivity and information (2000, 2025, 2050, 2075, 2100)

Activity

Activity levels of individuals measure their participation in the labour market, either as employees or as independent producers. They are usually recorded in statistics according to gender and age.

The meaning to be attached to activity levels has to be put in relation to economic and employment doctrines in the various countries: in some cases, this will refer only to population either having a paid job or listed in official unemployment records; in other cases this accounts for almost everybody in an age category corresponding to labour specification.

Activity levels of households is first determined by the structure of the households and the participation of households members in the labour market.

In most situations, the heads of urban households in the age classes below the retirement age, are considered as actives (this might not be the case in some rural areas where agriculture is still mainly a self-subsistence activity).

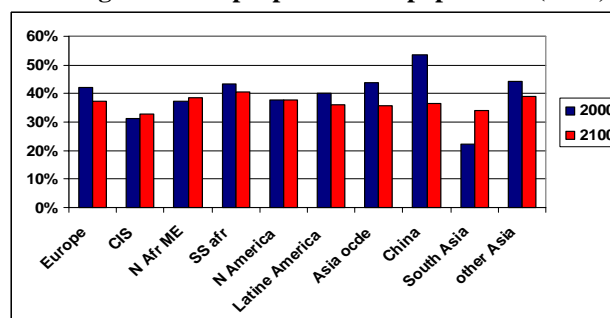
The participation of the second adult of the household in the labour market (in most cases the women), in the class ages below the retirement, varies strongly according to countries, without a clear relation with the development level (depends mainly on social and economic doctrines, but also on cultural values).

The participation of the children in the labour market is determined by the enrolment of children in school, and therefore by the information level: the highest the information level of a society, the longer the time spent by children in the education system, the later these children participate in paid labour.

In the Mid-Pop scenario, we assume that a double convergence will occur across the world regions:

the retirement age will become similar everywhere, around 65;

the participation of the second adult of the household in the labour market will saturate around 70% (or 85% in average for all adults below 65).

Figure 12: Percentage of active people on total population (2000, 2100)

2.1.3 Time budgets

The structure of time-use of people, the so called time-budgets, is the third main driver of the needs of energy services. Time-budgets drive the needs of energy services in three ways⁶.

In some socio-cultural functions, where the utility of time is low, there is a query for equipment devices and external services which allow to save time (in particular the food function); consequently, the needs of energy services diversify and increase along with the decrease in time-use: eating a ready-made frozen dish saves a lot of cooking time, but result in needs for conservation in house and needs to prepare, cook, freeze and store the food in the food production system.

In some other functions, where the utility of time is high (in particular self-accomplishment), the query for additional time result in additional equipment devices and diversify and increase the needs of energy services: this is the case with most of the new electronic devices, first with TV.

The income of the households is a direct consequent of the time spent in working for money from households members, and income drives the purchase of goods and services which in turn diversify and increase the needs of energy services.

In VLEEM scenarios, the issue of the time-budgets has been simplified to two main structural evolutions:

the substitution of time for working for money, for time for the food function (mainly in developing countries)

the substitution of time for self-accomplishment, for time for working for money (mainly in post-industrialised countries).

Time for mobility has been kept constant (Zahavi conjecture).

Time used in the food function⁷

As shown on the graphic below (fig 7), large discrepancies exist today among world regions as regard the time spent in the food function. These discrepancies do reflect the differences in development levels, household structure and culture. If we express the development level with the information level (because of the strong relation with labour productivity), we can classify the world regions in 3 groups :

a first group with a small information level and a high time budget for the food function SSAf, South Asia, China and Other Asia (about 6 hours per day)

a second group, also with a small information level, but a lower time budget for the food function: North Africa and Middle East , Latin America (less than 4 hours per day)

a last group with high information levels and low time budget for the food function (Europe, OECD Asia, North America and CIS; less than 3 hours per day).

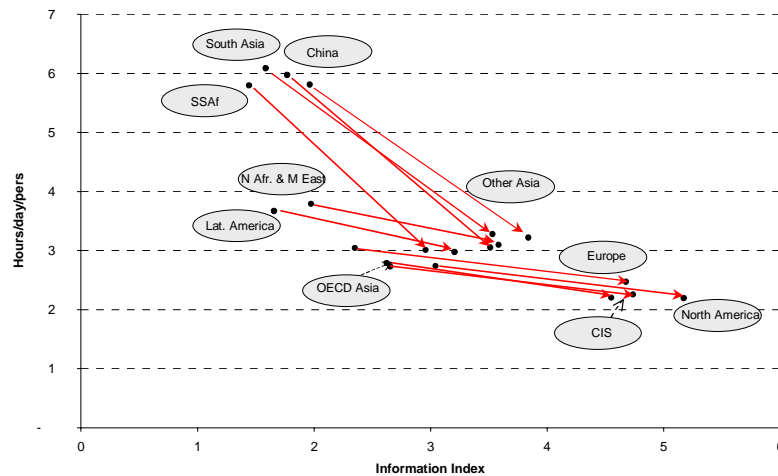
In the Mid-Pop scenario, we assume that globalisation leads to some harmonisation in life styles and consumption pattern all over the world, driven by more economically advanced countries. One of the result is that along with the progression of the information level in the less developed countries, the time spent for the food function tends to converge to the situation experienced today in the more industrialised countries, around 3 h/day. For the more

⁶ On theoretical foundations of the prospective assessment of the time-budgets, see VLEEM2, mid-term report, annex 2, in www.VLEEM.org

⁷ On data and validation of the relation between time budget and development, see VLEEM1, final report, annex 1

industrialised and “informed” regions the time spent in this function is expected to decrease even slightly more, to approximately 2.5 hours per day.

Figure 13: Time use for food and information (2000, 2100)



Time used in the shelter function⁸

Some discrepancies also exist today across the world as regard the time spent in the shelter function. These seem to have two main origins: habits⁹ and structure of households according to the age of the head. There is no direct link with the development level, as expressed by the information level.

The world regions can be classified in three groups:

South Asia, China, Other Asia, CIS and Ssaf , with a high time budget for shelter (about 13.5 hours per day)

Lat America, North Africa and Middle East, OECD Asia: with a medium time budget, about 12 hours per day

Europe and North America, with a low time budget, about 10.5 hours per day .

In the Mid-Pop scenario, we have assumed that the “habits” component will not change over time: for a same class of household (age of the head), the time budget for this function is assumed to remain constant for ever. But the structure of the households is expected to change (see above), and this would result everywhere to an increase in the average time budget for this function, more or less pronounced depending on the strength of the demographic transition.

⁸ On data and validation of the relation between time budget and development, see VLEEM1, final report, annex 1

⁹ Differences in habits reflect in fact two things, which cannot be really separated out: actual differences in the time spent for sleeping, hygien, housework, and differences in the definitions of the component of the function according to national surveys (statistical discrepancies)

*Time used for working for money*¹⁰

The time used for working for money is the result of three basic influences:
the activity level of the population and the participation in the paid jobs
the labour regulations: hours/day, holidays, retirement
the level of education

This time is more or less productive, according to the information level of the country, the employment policy and the statistical meaning attached to activity and jobs.

Therefore, there is no clear relation between the time spent for working for money and the level of development. Nevertheless, the world regions can be roughly classified in 2000 in 2 groups (with the exception of South Asia, see fig10 below):

Regions with a high information level, where people spend between 1.5 and 2 hours per day for working for money (life average)

Regions with a low information level, where people spend more time at work (for money) , between 2.5 to 3 hours per day

In the Mid-Pop scenario, we have considered three basic assumptions which have direct consequences on the time budget for working for money:

education, which interacts strongly with productivity and economic development through information, is supposed to develop everywhere, on a similar model to that experienced in industrialised countries, with a similar impact on productivity and economic growth (although it reduces the time spent at paid jobs);*

labour regulations tend to progressively harmonize all over the world through the globalisation process, resulting in reducing the time budget for paid jobs

restrictions to the access of women to the paid jobs which still exist in various parts of the world are progressively removed.

These assumptions lead to some convergence of the overall working hours per capita to about 1500 (with similar demographic structure) and the overall working hours per employee to about 4500.

At present, we have two groups of regions:

Sub Saharan Africa, China and Other Asia with overall working hours less than 1500 hours per capita and 4500 hours per employee (combination of high activity rate, low utilisation rate of employed people and demographic structure) : these regions are assumed to increase to 1500 per capita or 4500 per employee with the rise of the information level.

Lat America, North Africa and Middle East with working hours more than 1500 hours per capita and 4500 hours per employee (combination of low activity rate, high utilisation rate of employed people and demographic structure) : these regions are assumed to decrease to 1500 per capita or 4500 per employee with the rise of the information index.

¹⁰ On data and validation of the relation between time budget and development, see VLEEM1, final report, annex 1

Figure 14: Working hours per capita and index (2000, 2100)

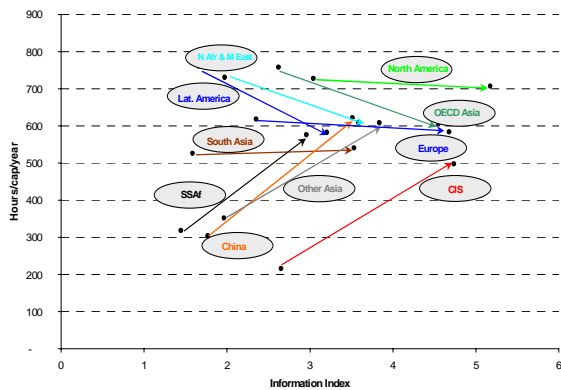
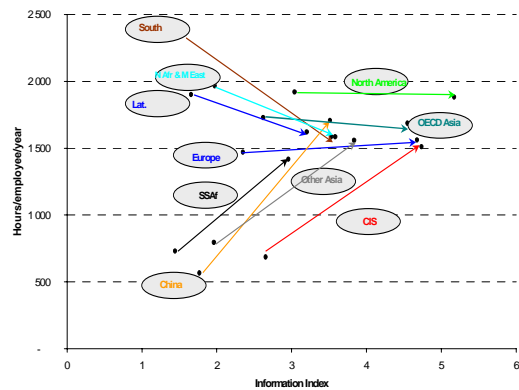
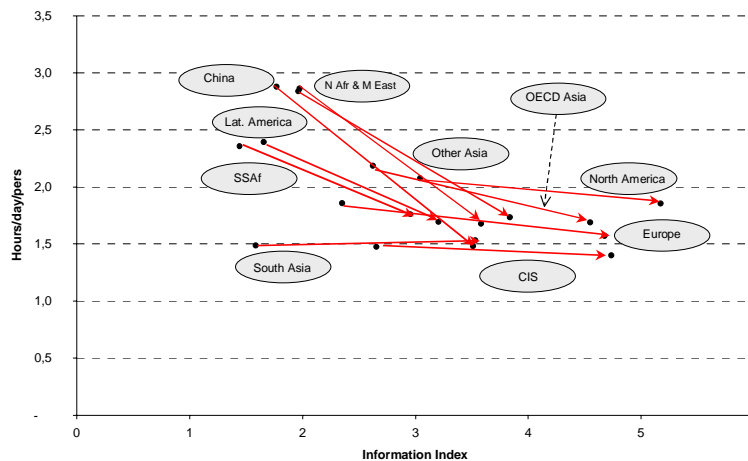


Figure 15: Working hours per employee Information and Information index (2000, 2100)



One question remains, which has been partially solved in the Mid-Pop scenario: the trade off between getting more money through more working hours and getting more time for self-accomplishment. This question has been debated from a theoretical point of view since the sixties¹¹, without nevertheless reaching a consensus. Two “models” seem to exist: the “US model” in which the marginal hourly salary over compensates the utility of the marginal hour in self-accomplishment (result: the people try to work more), and the “European model” in which it is the contrary (which explains the continuous request from trade-union for working less over the past century). In the Mid-Pop scenario, we have assumed that the US and Europe continues to behave as in the past, and that the world regions adopt the European model.

Figure 16: Time use for labour and information (2000, 2100)



Time used in the self-accomplishment function¹²

Large discrepancies do exist among world regions as regard the time spent for self-accomplishment, with a major cause: the level of development.

¹¹ see

¹² On data and validation of the relation between time budget and development, see VLEEM1, final report, annex 1

2 groups of regions can indeed be separated out:

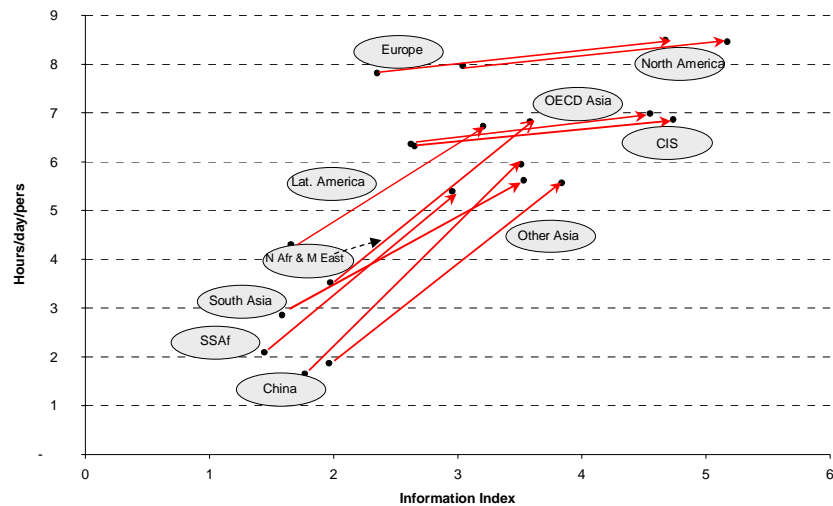
The world regions with a high information index, where people spend between 6 and 8 hours per day for self accomplishment (mostly industrialised countries);

The world regions with a low information index, where people spend between 2 to 4 hours per day for self accomplishment.

In VLEEM, we assume that the time budget for self accomplishment is the “swing time budget” up to 24 hours a day. It means that it is determined by the evolution of the time budget for the other functions (above), the time budget for working for money and the time budget for mobility (kept constant at one hour a day).

The result of all assumptions above is a tremendous increase in the time for self accomplishment in the developing world, and a slight increase in the industrialised world.

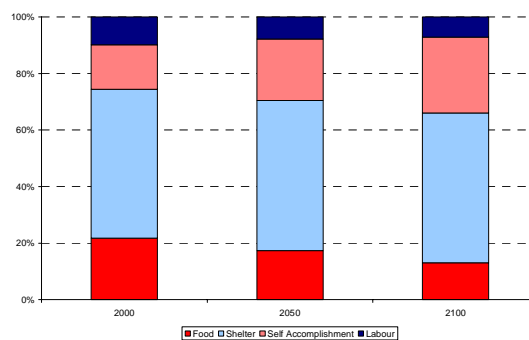
Figure 17: Time use for self accomplishment and information (2000,2100)



Time budget structures

In average for the world, we expect in the mid-pop scenario a decrease of share of the time budget for food from 22% in 2000 to 13% in 2100 and for labour, from 10% to 7%; an increase of the time budget for self accomplishment from 16% in 2000 to 27% in 2100 and a stabilisation of the time budget for shelter (53%).

Figure 18: Distribution of the time budgets (world)



2.1.4 Production, capital building and wealth

Production and economic development

In VLEEM-BASES, the growth of the economic production over the very long term is driven by two basic factors: labour (number of working hours) and information (productivity of the labour hour).

When comparing the economic situations of the various regions and countries over the world in 2000, it appears that the discrepancies in the production per working hour (measured with the GDP per working hour at purchasing power parity and the labour hours calculated in VLEEM) do not reflect properly the differences in information levels. This apparent contradiction results in fact from the way the working hours are calculated in VLEEM. Consistently with the overall modelling principles of BASES, working hours are calculated as the active population multiplied by the time budget for working for money. This calculation indicates the global availability of labour, but not what is actually required to run the existing physical production facilities (physical capital) and the related services, with the current information level of the society. The relative ratio between both quantities measures in fact the rate of actual use of the production potential of the country/region.

In the very long term, the evolution of this ratio is driven mostly by the fluidity of the financial capital across the world: the lowest the ratio, the highest the investment opportunities.

In a first attempt, we have assumed that, worldwide, the global savings will be always sufficient to finance the global investment required by the growth of the production as resulting from the two drivers indicated above.

In the Mid-Pop scenario, we have also assumed that existing barriers to the movement of financial capital worldwide will be progressively removed in an increasingly more peaceful and cooperative world (see the storyline of the Mid-Pop scenario in the Chapter 1 above). As a consequence, the rate of use of the production potential will tend to increase everywhere up to a technical limit around 95% (5% structural unemployment). This corresponds to a rate of use of the maximum labour possibilities (100% activity rate for everybody between end of school and retirement) of 85% (see table 26 below).

The consequence of all assumptions above is a global convergence in the economic development as measured by the production per capita (proxy with the GDP per capita at purchasing power parity). This convergence is rather strong in relative terms, although absolute difference in production per capita still increases between the more and the less advanced countries in the world.

Figure 19: Index of use of labour possibilities (2000, 2100)

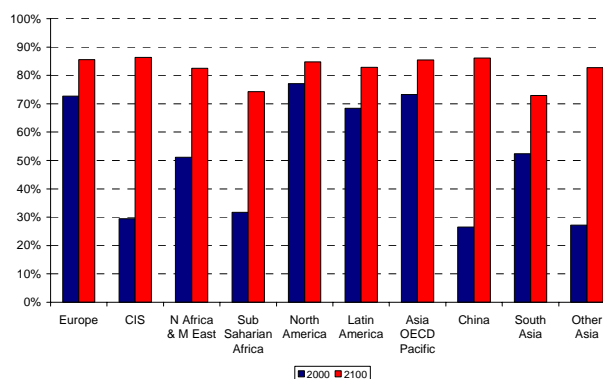
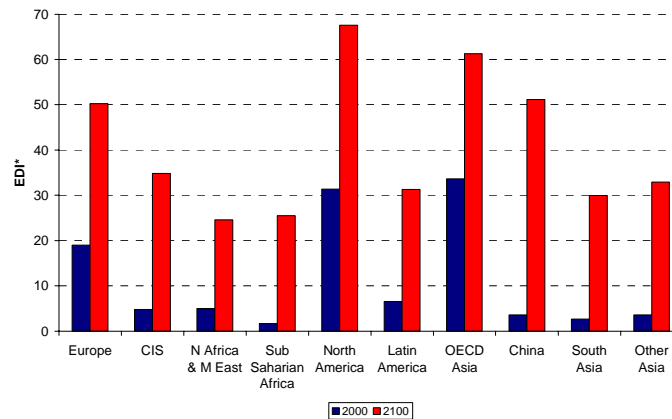


Figure 20: Economic development (2000, 2100)

* EDI, Economic Development Index, is constructed on the basis of GDP per capita at purchasing power parity at base year.

From economic development to wealth and welfare

The growth of the economic production per capita participates to the increase of the affluence of individuals, the wealth of the country and the general welfare in the country. This is obviously true within a country with no external trade: the more is produced, the more people have consumption opportunities, and the more people can consume. But this is also true in global terms, at the worldwide level, through another mechanism: the bigger the production of a country, the closer the value of the currency of that country on the financial market and its actual purchasing power on the world market. For example, in a country with a low GDP/capita (expressed in i.e. at current exchange rate), an average worker can buy two shirts in his country with one day salary; if he travels to the US and changes its salary in US\$, then he can buy there only one shirt. After many years of a stronger economic development of his country as compared to the US, this worker will be able to purchase now 10 shirts with one day salary in his country (consumption level multiplied by 5 because of the production increase), but 8 shirts in the US (instead of 5), because of the improvement of the exchange parity of his currency against the US\$. He is five times more rich in his country, but eight times more rich at the worldwide level.

In the Mid-Pop scenario, in which globalisation is assumed to be leading the world economic development, differences in growth rates of production as compared to the world more industrialised countries (North America, Europe and OECD-Asia) result in a reduction of the gap between the exchange rate and the purchasing power worldwide of the currencies, and in even bigger differences in the growth rates of wealth and affluence (measured in worldwide ability to purchase goods and services).

2.2 Needs of energy services according to main socio-cultural functions in the world, from 2000 to 2100

“Needs of energy services” is a different concept than “needs of useful energy” or “final energy demand”. Energy services refer to realities like “food conservation”, “in-door climate”, “mobility in individual modes”, etc...

In practice, the measurement of the needs of energy services require various measurement units which are specific to the energy services: “volume of food to be conserved”, “dwellings to be climatized”, “kilometres in individual modes”, etc...

But all needs of energy services actually generate first a need of useful energy, and second a final energy demand. The relation between the needs of energy services and the related need of useful energy is entirely determined by the technology paradigm in which the needs of energy services are expressed. Conserving food can be done either in traditional storage facilities (“garde-manger”, cellar, ...) without any need of useful energy, or in refrigerators (with a related need of “frigories”) or in a vacuum space (with a related need of mechanical power).

This means that within a given technology paradigm, we can easily convert the needs of energy services into needs of useful energy, but that this conversion is not relevant anymore with a different technology paradigm. This is the problem that we had to solve in VLEEM-BASES. At base year, 2000, all needs of energy services can be converted in needs of useful energy, and it makes sense to compare and aggregate them. But this conversion made for 2000 values is not relevant any more in 2050 or 2100, at least in the cases where a major change in the technology paradigm is considered.

The solution adopted in VLEEM-BASES to this problem is twofold:

To support the structural analysis of the needs of energy services (which requires aggregation and comparability): the needs of energy services are eventually expressed in the same unit, PJ, for all years, using the conversion coefficients to useful energy at base year (2000), i.e. corresponding to the technology paradigm of 2000. This makes possible to build up matrices of energy services according to quality criteria (exergy, spatial density, unit power), which is the basic instrument for the structural analysis.

To support the dynamic analysis of the needs of energy services (which requires homogeneity across time): the development of the needs of energy services over time is captured with indexes based on specific units for each energy service.

In this chapter, all the graphs and comments below are based on the indexes. Aggregated figures are provided whenever necessary. The corresponding indexes are calculated combining both approaches.

2.2.1 Food function

Doubling the needs of energy services for food worldwide from 2000 to 2100

The three main drivers of the needs of energy services for the food function are the time used in the function, the affluence and the population. The less time the people spend in the function, the less time is devoted to cooking, the more household appliances they use, and the more they eat food prepared outdoor. The more wealthy they are, the bigger and more diversified appliances they have, and the more diversified and elaborated industrialised and ready-made food product they can buy.

Depending on the region, its climate and arable land, the food production system –from primary agriculture to ready-made industrial dishes – may have a magnitude from far below up to far above the food requirement of the people of the region. This explains why large differences in the overall needs of energy services of the food function per capita can be observed at base year among regions with similar time use and the affluence pattern.

This observation does not contradict the statistical confirmation of the general relations between the needs of energy services per capita in the one side, the time use and the affluence on the other side, as shown on figures 28 and 29 below.

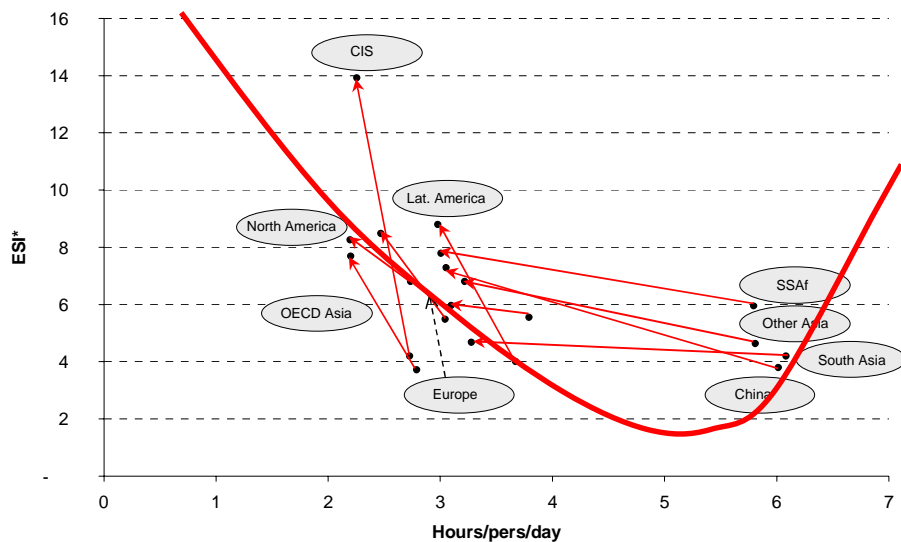
In the Mid-Pop scenario, we have assumed that the relation observed today in industrialised countries between the needs of energy services inside the homes, the time use and the affluence constitutes a reference towards which the less developed countries will converge with the progress of the information level.

Similarly, we have assumed that the needs of energy services in the food production system per unit of primary food product will change with the affluence similarly to what has been experienced in industrialised countries of today.

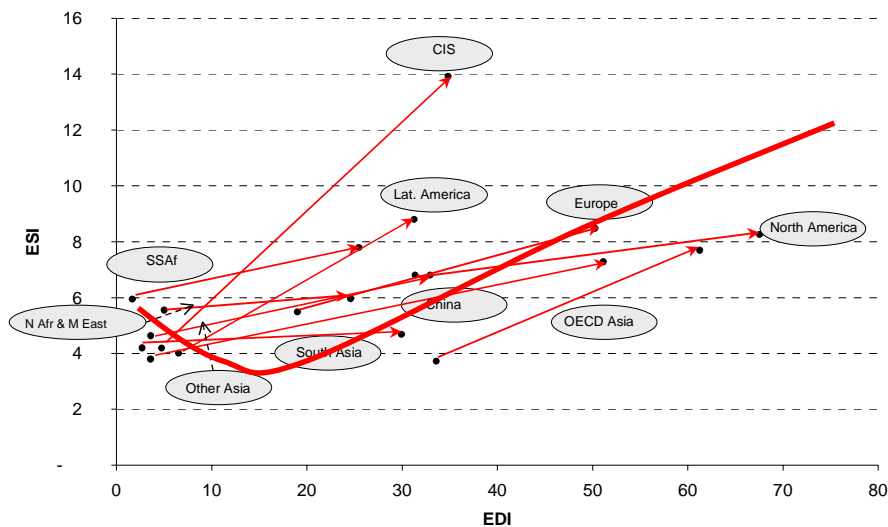
The quantity of primary food products produced and processed are supposed to be entirely determined by the availability of arable land at the turn of the century (and the use of fertilizers of course). Some regions of the world with low population density, like the CIS for instance, are therefore considered to have large arable land surpluses (as compared to domestic food requirement) that drive a steady increase in the needs of energy services of the food production system (in particular because of the climate change).

The needs of energy services for the food function worldwide are calculated to double from 2000 to 2100 in the Mid-Pop scenario, while the world population would increase by one third. The range of needs of energy services per capita, which is between 4 and 7 today, would be from 5 to 9 in 2100, with the exception of the CIS which would reach 14 (a huge land for a small population).

Figure 21: Needs of energy services for food and time budget (2000, 2100)



* ESI, Energy Services Index, is constructed on the basis of the useful energy requirement per capita at base year, with conventional end-use efficiencies.

Figure 22: Needs of energy services for food and economic development

* EDI, Economic Development Index, is constructed on the basis of GDP per capita at purchasing power parity at base year.

An increasing weight of the food production system and high exergy requirement worldwide

The evolution of the needs of energy services per capita goes along with a change in the structure of these needs: when information level increases, the need of energy services for cooking food decreases while the needs related to household appliances (preparation, conservation, cleaning) increase, as well as the needs of the food production system, first agriculture, then food processing. The needs of the food processing industries are those which increase the fastest. In the industrialised countries of today, non households needs of energy services (outdoor: agriculture, agro-food industry) represent already the biggest part of the total needs for the food function.

In 2100, the outdoor needs are calculated by VLEEM-BASES to represent roughly half of the total needs in the whole world, against 30% in 2000. In the meantime, the needs of energy services related to cooking food are expected to decrease significantly, roughly by one third worldwide.

In Europe, where the food production system already accounts for 58% of the total needs, the share of outdoor needs is expected to grow up to 68%, while needs related to cooking food will decline by 17% in absolute terms.

Because of this structural evolution, another change in the structure of the needs according to quality criteria goes along the overall increase of the needs per capita. The needs that involve low exergy requirement (basically cleaning) increase moderately, while those involving high stationary exergy requirement (mechanical power, electrical power) increase fast, representing more than half of the total needs almost everywhere in 2100 (against some 20% today worldwide). For the whole world, the total needs of energy services corresponding to medium exergy requirement (medium temperature heat) is expected to decrease a little in absolute terms.

In Europe, the share of the needs requiring high exergy would climb from 41% today up to 52% in 2100, while the share of those requiring medium exergy would decline from 47% to 39%.

Figure 23: Needs of energy services for food according to energy service category (2000, 2100)

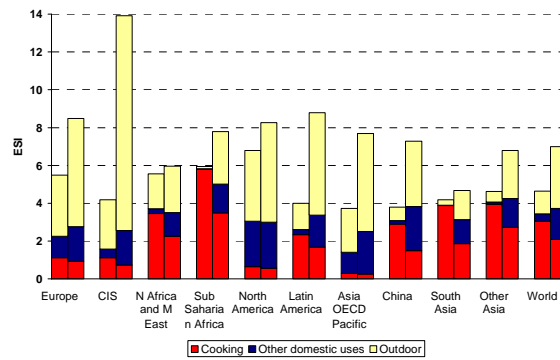
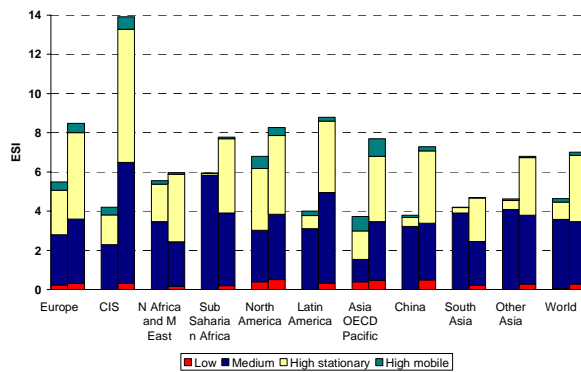


Figure 24: Needs of energy services for food according to exergy level (2000, 2100)



A drastic concentration of the needs

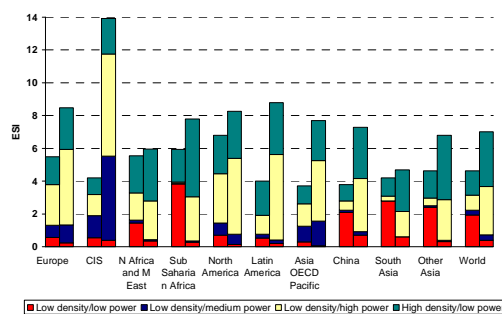
In 2000, the needs of energy services for the food function are rather diffuse worldwide, but already highly concentrated in the industrialised countries: the share of low density/low unit power needs represents about 42% of the total needs in average for the world, but only 10% in Europe or in the US. In the developing world, Sub-Saharan Africa, South Asia, Other Asia and China, the share of low density/low unit power needs can account for 65% of the total needs.

In the Mid-Pop scenario, two major influences combine to increase drastically the share of the concentrated needs, either high unit power or high spatial density, everywhere:

- the development of the food processing industry
- the urbanisation

Worldwide, the share of the concentrated needs is therefore calculated by VLEEM-BASES to increase from 52% to 90% of the total needs, from 2000 to 2100. In the same time, this share is expected to increase from 76% to 84% in Europe.

Figure 25: Needs of energy services for food according to density/power category (2000, 2100)



2.2.2 Shelter

Nearly tripling the needs of energy services for shelter worldwide from 2000 to 2100

The three main drivers of the needs of energy services for the shelter function are the affluence, the dwelling stock and the population. The more affluent the people, the bigger the dwelling area per capita, and the more equipped the dwelling for comfort and daily life amenities. The smaller the average size of the households, the larger the dwelling stock, the floor area and the dwelling equipment per capita.

Differences in climatic conditions explains the huge gap in the needs of energy services for shelter per capita between the cold regions of the Northern hemisphere and the warm regions in tropical areas, both sides of the equator: about 8 for OECD Asia, 12 for Europe, 16 for CIS and 21 for North America, against 0.6 to 2.8 in the developing world.

But in industrialised regions where both types of climate exist (the US or Japan for instance), the difference in needs of people living in both areas are much smaller: needs are different, but of a similar magnitude.

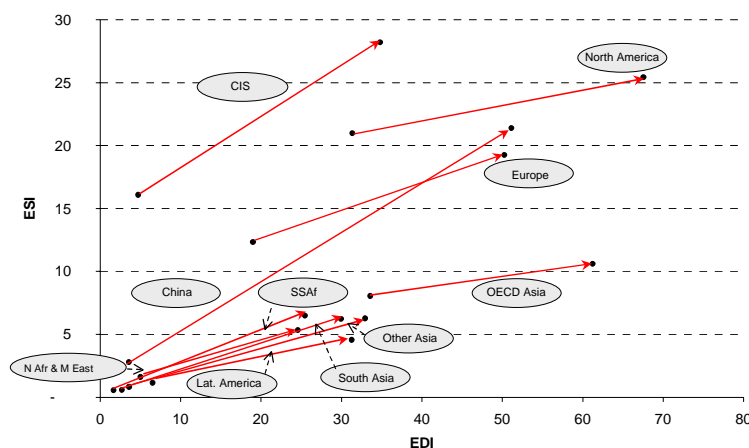
In the Mid-Pop scenario, we have assumed that the relation observed today in industrialised countries between the needs of energy services inside the homes and the affluence constitutes a reference towards which the less developed countries will converge with the progress of the information level, but at different speed and with final levels depending on the climatic conditions.

The needs of energy services in the dwelling production system per dwelling unit are determined by the construction techniques and building materials used, which are assumed to harmonize worldwide before 2100.

The number of dwellings built and maintained is entirely determined by the number of households in each living area: urban, sub-urban, rural, and by the replacement rate of the existing dwelling stock.

The needs of energy services for the shelter function worldwide are calculated to almost triple from 2000 to 2100 in the Mid-Pop scenario, while the number of households would double. The range of needs of energy services per capita, which is between 0.6 and 21 today, would be from 5 to 28 in 2100.

Figure 26: Needs of energy services for shelter and economic development (2000, 2100)



Thermal comfort drives the needs

Thermal comfort (space heating and cooling) is, and will remain, the main need of energy service for shelter. It represents 60% of the needs for shelter in 2000 and 66% in 2100 at a world level. It is not expected to grow much in industrialised countries of today, where it is already very much developed. It is the contrary in the developing world, both cold and warm climatic conditions, where increase in affluence and living standards is expected to drive a strong development of thermal comfort appliances, central space heating and air cooling.

In Europe, thermal comfort accounts today for 67% of the needs of energy services of the shelter function, and this share is expected to grow up to 70% by 2100.

Second to thermal comfort, sanitary comfort is expected to rise everywhere, in particular in developing countries where it is rather inexistent today. Of course, differences in climatic conditions will continue to explain large discrepancies in the need per capita, the warmer the average outdoor temperature, the less the necessity to warm water for sanitary comfort purposes. The share of sanitary comfort in the total needs for energy services of the shelter function is calculated to decrease, from 18% in 2000 down to 12% in 2100: industrialised countries of today are already well equipped, and the increase in the developing world will be limited, due to the climatic conditions.

In Europe, sanitary comfort accounts today for 19% of the needs of energy services of the shelter function, and this share is expected to decline down to 16% by 2100.

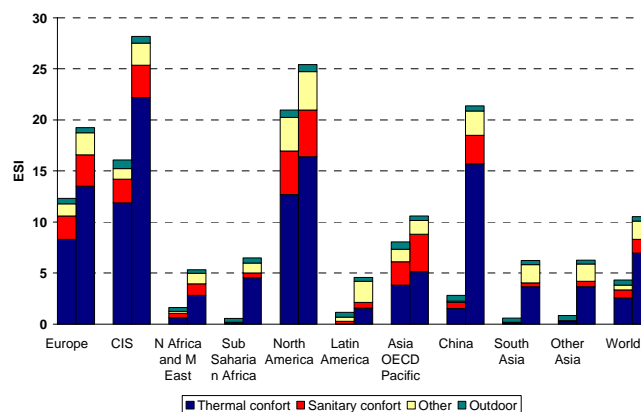
Lighting is the main component of the last group of energy services of the shelter function, along with cleaning appliances. These are expected to experience also a fast development, in particular in the developing world, where they will be strongly driven by the growth of affluence. In the industrialised countries of today, where households equipment is already very high, the driving force of affluence is expected to be much weaker.

In Europe, households appliances and lighting accounts today for 9% of the needs of energy services of the shelter function, and this share is expected to grow up to 11% by 2100.

The share of the dwelling construction and maintenance in the needs of energy services, which is today around 11% worldwide, is calculated to decrease drastically at the end of the century, towards 4%.

In Europe, the share of the dwelling production system in the total energy needs of the shelter function is already rather low, 4%, and is expected to decline even further to 2%.

Figure 27: Needs of energy services for shelter according to energy service category (2000, 2100)



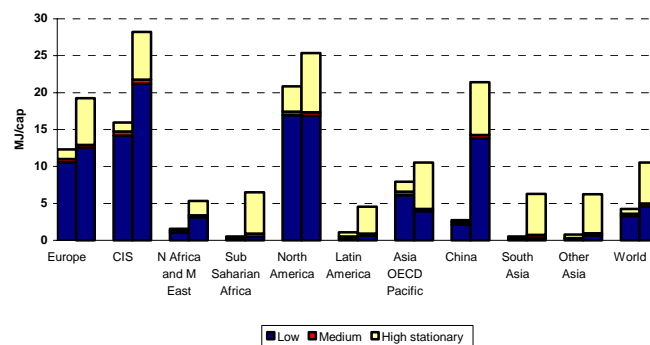
High exergy takes the bulk of additional needs of energy services from 2000 to 2100

In 2000, almost 77% of the needs of energy services for shelter worldwide require low exergy supply (space heating and hot water), only 15% high stationary exergy. From 2000 to 2100, VLEEM-BASES calculates a tremendous increase of the high stationary exergy (cooling, lighting and cleaning), up to more than half of the total needs, while low exergy needs will decline (in relative terms) down to 44% of the total. Nearly 80% of the absolute increase of the needs from 2000 to 2100 correspond to high exergy (which basically means electricity, either from the grid or generated in-situ).

In Europe, where 86% of the needs are low exergy needs and 11% high stationary exergy in 2000, the change in the structure will not be so radical, because of the prevailing climatic conditions. Low exergy needs will still account for more than 65% of the total in 2100, while the share of high stationary exergy will rise up to “only” 33%.

The proportion of medium exergy (industrial heat basically) is and is expected to remain small everywhere.

Figure 28: Needs of energy services for shelter according to exergy level (2000, 2100)

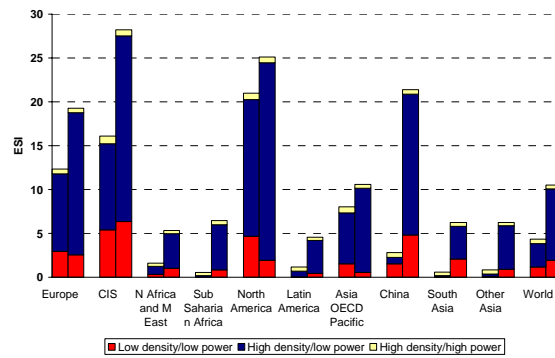


Towards a spatial densification of the needs of energy services of the shelter function

The high density/low power needs are the main needs for shelter almost everywhere except China, where low density/low power account for more than half of the total needs. As the main consequence of the urbanisation process expected everywhere, the share of the high density needs is calculated to increase, from 61% of the total needs in 2000 to 77% in 2100.

One of the most striking feature of the needs of energy services for shelter is their low unit power requirement: almost 90% of the needs today are of this kind, and this proportion is calculated to increase to 95% at the turn of the century. This means that a very high share of these needs can be supplied, now and in the distant future, with very diffuse energy sources or supplies.

The same remark can be made for Europe, where the low density/low power needs are even calculated to decrease in absolute terms from 2000 to 2100.

Figure 29: Needs of energy services for shelter according to density/power categories (2000, 2100)

2.2.3 Self accomplishment

The fastest growth of the needs of energy services worldwide from 2000 to 2100

The needs of energy services for self-accomplishment in-door¹³ are calculated to grow 16 times from 2000 to 2100 worldwide in the Mid-Pop scenario.

The main drivers of the needs of energy services per capita for the self accomplishment function are the time-use, the affluence and the information level. The more affluent the people, the more equipped the dwelling for information, communication and in-door electronic leisure. The smaller the average size of the households, the larger the dwelling equipment per capita. The more time available for self-accomplishment, the more use of the dwelling equipment.

Information plays a double role: it drives downwards the share of time used for in-door activities in the self accomplishment time-budget (more time available, more opportunities for outdoor activities), and it drives upwards the share of the time used with ICT's within the in-door time-use (the higher the information level, the more availability of ICT's).

In all story-lines, we have assumed that industrialisation and marketing of goods and services related to information, communication and self-accomplishment will drive the final consumption in the industrialised countries of today for the whole next century. The main reason behind is that only the use of such goods and services for leisure time is likely to increase the utility of the time spent in these activities at a level comparable with the value of time in working for money (otherwise, there is no reason for people to look for more time for self-accomplishment and less time for working for money; see above, chapter 1, about the theoretical foundation of this assumption). This is also assumed to be the case for the developing world, but at a later stage in the century.

All needs of energy services for the in-door self-accomplishment are high exergy needs (basically electricity), low unit power: this means that can be supplied with electricity either distributed through grids or generated in-situ.

¹³ needs of energy services for self-accomplishment out-door (sports, cultural activities, visiting friends and relatives, tourism, etc..) are basically related to mobility, and accounted for in the mobility function.

In the Mid-Pop scenario, we have assumed that the relation observed today between the needs of energy services in-door per hour of in-door self accomplishment time budget, the information level and the affluence constitutes a reference for all countries of the world, and for the whole century.

The needs of energy services for the self-accomplishment function worldwide are calculated to be multiplied by 16 from 2000 to 2100, while the population would increase by only 36%. The model simulates a very strong increase of the time use for self accomplishment for the less developed regions (from about 1.5-3.5 hours per day to about 5-7 hours per day on average) and a strong increase of the energy needs with the increase of the time use for self accomplishment.

For the most developed regions, the model simulates a slight increase of the time use for self-accomplishment (which was already high in 2000), but a strong rise of the energy needs per capita (between a factor 3 and a factor 11, factor 9 for Europe).

Figure 30: Energy needs for self accomplishment and time budget (2000, 2100)

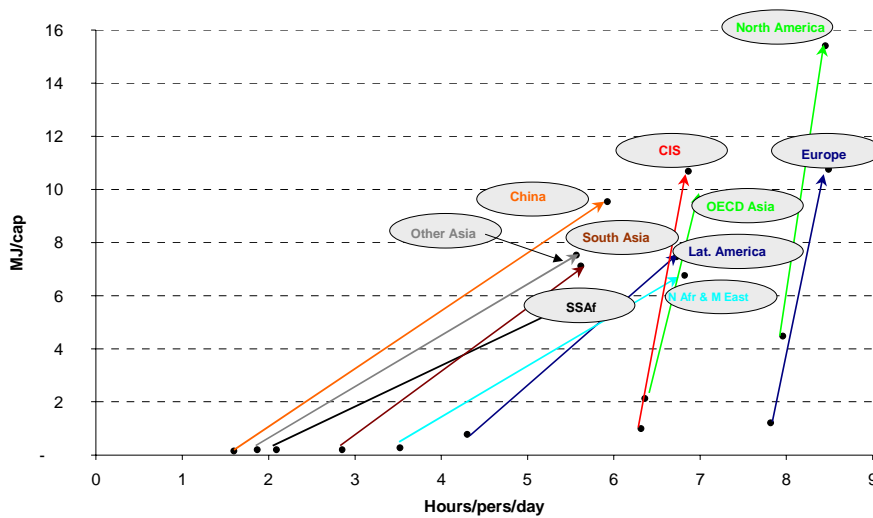
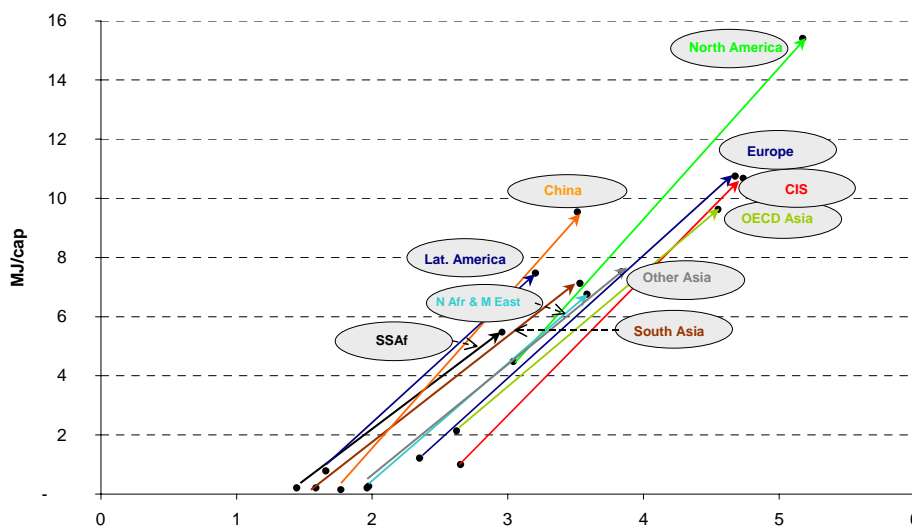


Figure 31: Energy needs for self accomplishment and information index (2000, 2100)



2.2.4 Transport

More than quintupling the needs of energy services for mobility worldwide from 2000 to 2100

The three main drivers of the needs of energy services for the mobility function are the affluence, the transport infrastructure and organisation, and the population. The more affluent the people, the more equipped they are with private vehicles, the more they can purchase speed to go further, the higher the quantity and value of goods to be transported, the higher the value of the freight speed. Transport infrastructures and organisation determine both the spatial distribution of production activities worldwide and the urbanisation pattern in the one side, the relative competitiveness/attractivity of transport modes in competition in the other side.

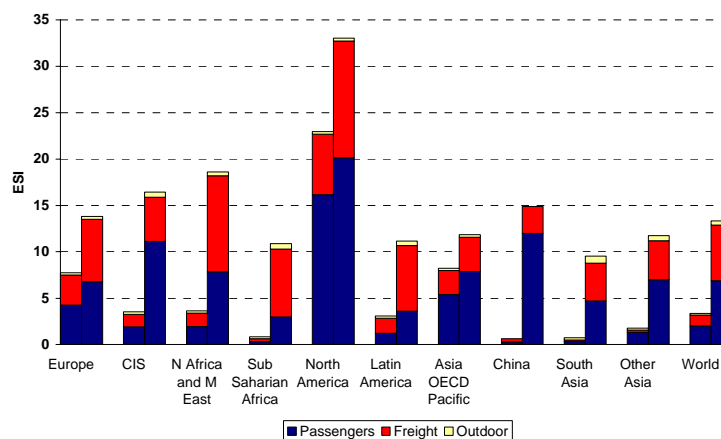
There are strong differences in transport infrastructures and organisation among the industrialised countries of today, which explain the discrepancies observed today in the needs of energy services per capita for mobility among countries with similar affluence level. These differences have historical origins, linked with the spatial dimension of the country, the population density, the urbanisation pattern and the history of the transport system.

In the Mid-Pop scenario, we have assumed that the relation observed today worldwide between the average speed of personal and freight movement and the affluence constitutes a reference that will apply to all countries for the whole century.

The needs of energy services in the transport infrastructures production system are determined by the traffics of persons and freight, with a relation which is assumed to harmonize worldwide before 2100.

The needs of energy services for the mobility function worldwide are calculated to be multiplied by around five from 2000 to 2100 in the Mid-Pop scenario, while the population would grow by 36%. The range of needs of energy services per capita, which is between 0.6 and 23 MJ/cap today, would be from 10 to 33 in 2100. In Europe, the needs of energy services per capita will almost double, from 7.7 today up to 14 in 2100.

Figure 32: Needs of energy services for transport (2000, 2100)



Passengers mobility

The time budget for mobility has been kept constant everywhere at roughly the same level, one hour in average per person and per day. This assumption, which is based on Zahavi's proposition¹⁴, has been validated since then by a number of studies, although some doubt arised recently, resulting from the analysis of the time use for out-door self-accomplishment activities (in particular tourism)¹⁵.

Because of this time use constraint, any increase in the passenger mobility (km/capita/year) is a direct consequence of an increase of the average speed. This average speed is driven by the affluence, through an elasticity which has proved to be fairly stable over time and very similar from one country to another. Since the period on which this elasticity has been measured is entirely dominated by the road transport paradigm, one can assume that the observed value does reflect some property of this paradigm, and not a fundamental law of the mobility dynamics. In particular, the on-going research studies on "decoupling mobility from the economic growth"¹⁶ suggest that speed increase could be "decoupled" to some extent from the economic growth through a different organisation of the transport system, where a same accessibility could be organised with lower speed within the overall time-use constraint.¹⁷

Since every transport mode has a critical speed on each type of trip (urban versus regional versus long distance), there is a global relation between the average speed of passenger mobility, the structure of the mobility according to trip types and the relative share of the modes on each trip type. This relation does not imply that only one modal structure corresponds to one particular average speed, but that some modal structure are just not compatible with the average speed. In particular, the higher the share of long distance trips (because of the increase of the time available for out-door self-accomplishment), the higher the speed (because of the affluence and the value of time), the lower the contribution of private cars and other road modes to these trips (because their speed is limited). In the assessment of the modal allocation which are compatible with the speed constraint, another element has to be accounted for: the equipment of the households in private vehicles, and the annual use of these vehicles (km/year).

In most regions of the developing world, where slow modes still account for the bulk of the trips, the overall passenger mobility is in a range 2000-6000 km/cap per year in 2000. The situation is totally different in the industrialised countries of today, where road transport is already much developed : personal mobility reaches nearly 13000 km/cap per year in OECD Asia , 11 200 in Europe and more than 23 000 in North America .

In the Mid-Pop scenario, the model simulates a convergence of the mobility around the world in a range 12 000-20 000 km/cap per year because of the average speed increase. North America remains apart of the other regions with a very high mobility pattern: 29 000 km/cap per year. Household equipment in private vehicles is assumed to come soon to saturation in

¹⁴ See the final report of VLEEM1 and the annex 1 of this report for more details and references, in www.VLEEM.org

¹⁵ See Vincent Bagard PhD thesis, to be released May 2005, LET, University of Lyon

¹⁶ see for example the on-going international study carried out by the OECD on this subject

¹⁷ see in particular the first report of the research study carried out by Enerdata and the Laboratoire d'Economie des Transports for the French Ministry of Transport (PREDIT 3 research programme, 2004).

the industrialised countries of today, and to reach saturation before the turn of the century in most developing countries of today, because of the growth in affluence.

The share of private vehicles in persons mobility is calculated to decrease in industrialised countries of today, down to 41% in the USA and 69% in Europe (75% in 2000). In the developing world of today, it is calculated to increase first (up to 85% in Latine America in 2100, 69% in 2000 for example) and, for some more advanced regions to start decreasing before the turn of the century.

Figure 33: Passenger mobility and economic development (2000, 2100)

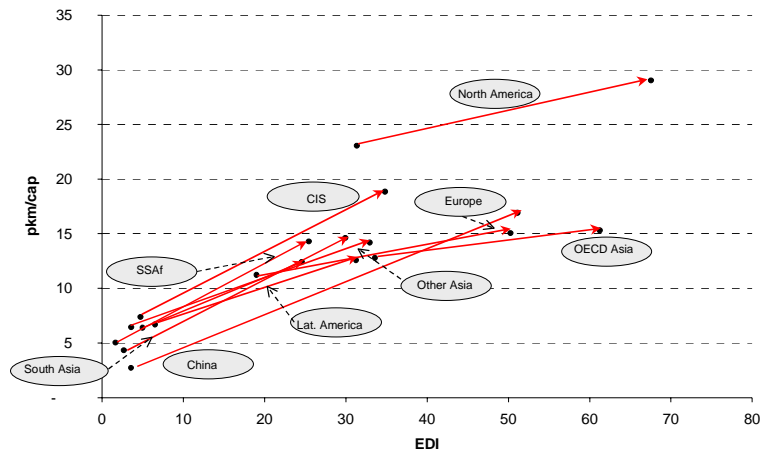
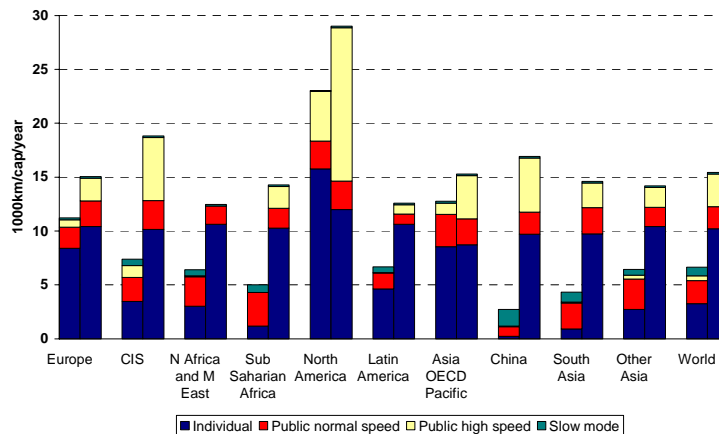


Figure 34: Passenger mobility per mode (2000, 2100)



Freight mobility

As for passengers, the average speed of the freight mobility is historically observed to increase with the economic production. This is a direct consequence of the fact that the value per ton of the goods transported increases with the economic production: this makes the time spent in transportation more and more expensive (immobilization cost) as compared to the cost of transportation, and moves the equilibrium point towards faster transport solutions.

Here also, every transport mode has a critical speed on each type of trip (urban versus regional versus long distance), which also depends on the quality of the infrastructures. There is a global relation between the average speed of freight mobility, the structure of the mobility according to the types of trips and goods, and the relative share of the modes on each

trip/good type. This relation does not imply that only one modal structure corresponds to one particular average speed, but that some modal structure are just not compatible with the average speed. In particular, the higher the share of long distance trips (because of the globalisation of trade), the higher the speed (because of the economic production), the lower the contribution of road modes to these trips (because their speed is limited).

In most regions of the developing world, where transport infrastructures are still poor and the economic production low, the overall freight mobility is in a range 1000-3000 ton-km/cap per year in 2000. In the industrialised countries of today, where road transport infrastructures are good and the economic production high, the range is between 5 000 and 15 000 ton-km/cap per year. This range in industrialised countries give an indication of the differences in freight mobility which come from the endowment in natural resources and from the geographic area on which freight activity currently takes place.

In the Mid-Pop scenario, there is a clear distinction among three groups of regions:

- a first group corresponding to regions with only one country of a very big size (USA, CIS, China), where the geographical dimension drives the freight mobility to high levels when the economic production develop (12 000 to 19 000 ton-km/cap per year in 2100)
- a second group corresponding to regions either with one big dominant country or highly economically integrated, for which the model calculates a convergence around 8 000 ton-km/cap per year (South Asia, Europe, Latine America)
- A third group with the other countries, where the freight mobility is calculated to remain close or below 5 000 ton-km/cap per year.

The share of road in freight mobility ranges from 10% to 91% among the world regions in 2000: this reflects huge differences in the historical development of the infrastructures, from countries like the USA, the CIS or China, where rail infrastructures have been widely developed to cope with the transportation of natural resources over long distances, and countries with almost no rail infrastructures, where everything has to be moved by road. In 2100, the model calculates a much reduced gap between the different world regions (33% to 96%), in particular because of the development of fast modes imposed by the speed constraint.

Figure 35: Freight mobility and economic development (2000, 2100)

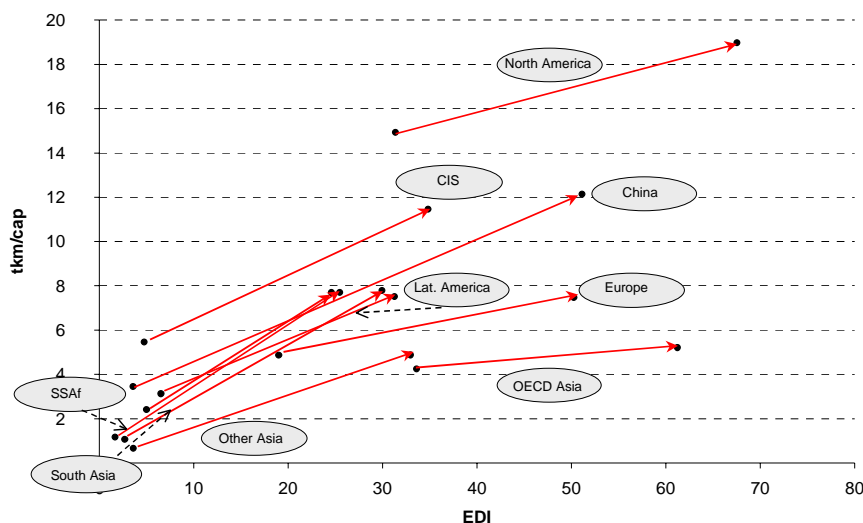
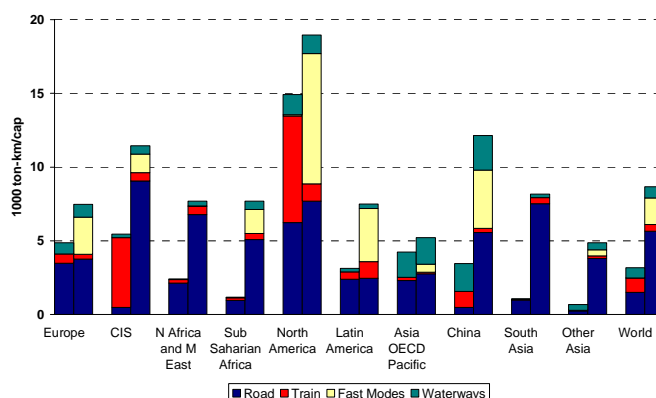


Figure 36: Freight mobility per mode (2000, 2100)

2.2.5 Other economic production

A moderate increase of the needs of energy services for the economic production up to 2100

Part of the economic production has already been assessed through the basic material requirement for the socio-cultural functions: production of food, of shelter, of transport infrastructures.

The rest of the economic production, the bulk part, corresponds to all primary, secondary and tertiary production activities. For reasons explained before¹⁸, the rest of the economic production is assessed as a single entity.

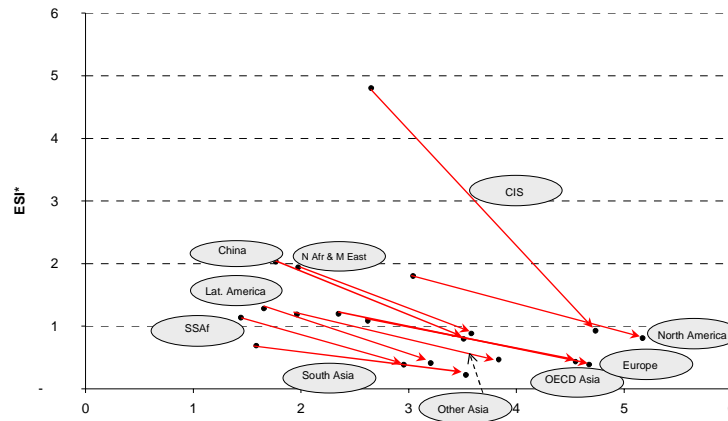
The needs of energy services of the overall economic production is entirely determined, in VLEEM-BASES, by the magnitude of the economic production and by the information level. The same global relation explains both the differences in the needs of energy services of the different regions in 2000, and the development of these needs over time up to the end of the century.

In the Mid-Pop scenario, the world economic production is calculated to be multiplied by 8 between 2000 and 2100, but the needs of energy services of the economic production is only calculated to increase by 220%. The reason is related to the global process of “dematerialisation” of the production considered in the scenario, which means that an increasing share of the world economic production will be made with high value, non material production, which express relatively very low needs of energy services. As already observed in the whole 20th century in industrialised countries of today, the average energy input in the economic production is calculated to decrease drastically everywhere from now to 2100.

In the more industrialised countries of today, the USA, Europe, OECD-Asia, the absolute magnitude of the needs of energy services is calculated to decrease slightly. In all the other regions, it is calculated to increase, in particular in China.

¹⁸ See VLEEM1 final report, annex 1, in www.VLEEM.org

Figure 37: Needs of energy services per unit of economic production and information (2000, 2100)



ESI: energy Service Index; based on the MJ/\$GDP ppp at base year

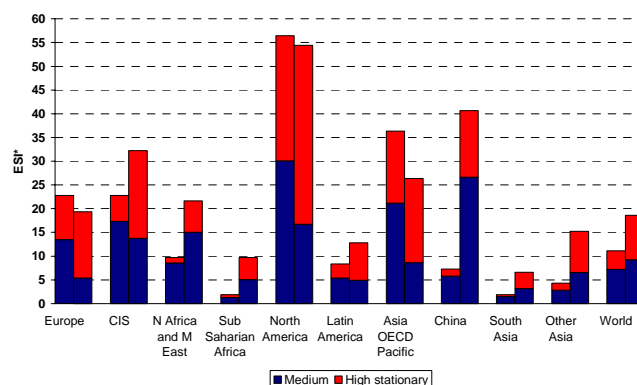
High stationary exergy takes the bulk of the increase of the needs of energy services

High stationary exergy needs of the production system are more related to the value incorporated in the materials processed by the system, while medium exergy needs are more related to the physical quantities which are processed in the system. The higher the level of information, the higher the average value per physical unit of material processed, the higher the share of high stationary exergy needs.

The needs of energy services for the production of food, shelter and transport infrastructures are mostly medium exergy, because strongly influenced by the processing of primary materials: steel, cement, bricks, glass, fertilizers, etc... Therefore, in the rest of the production, the share of high exergy needs is calculated to increase even faster than in average for the whole production system. Almost 75% of the increase of the needs of energy services between 2000 and 2100 correspond to high stationary exergy.

Because of the globalisation and its consequences on the location of basic industries worldwide, the change in the structure of needs according to exergy levels is expected to be very different according to regions. In industrialised countries of today, the medium exergy needs are calculated to decrease drastically in absolute terms; roughly by a factor 2, while the high exergy needs will still increase significantly. In developing countries of today, both types of needs are expected to increase, but as a higher speed for high exergy needs.

Figure 38: Needs of energy services per exergy levels (2000, 2100)



2.3 Visions of the world in 2100: uncertainties and consequences on energy related needs

Obviously, uncertainty is a master word when one tries to build any vision of the world in 2100!

In back-casting studies, nevertheless, uncertainty takes a particular meaning. It does not concern the probability to reach the target vision elaborated, but the intrinsic consistency of this vision.

In VLEEM-BASES, the vision of the world in 2100 described above results from certain fundamental assumptions as to the essence of the socio-economic development that we need now to discuss in order to understand how, and how much, these assumptions impact our vision.

But before, we will synthesize the main results of the Mid-Pop scenario.

2.3.1 The vision of the world in the Mid-Pop scenario in 2100: a synthesis

A strong influence of western life-styles and development pattern

In the Mid-Pop scenario, in 2100, most of the world population of the developing world of today is expected to enjoy a similar life-style and consumption pattern as those experienced by OECD countries during the last 20 years, with similar individual affluence. They will live in “hard” dwellings, about 30m² per inhabitant, with all commodities for climatic and sanitary comfort, housing equipment to substitute for time and pain in daily households tasks, and housing equipment for in-door leisure. Most of them will own private vehicles that they will use first for daily mobility, then for more distant travels; they will go for holidays and, increasingly, they will fly over long distances for tourism purposes.

As a consequence, their needs of energy services in 2100 will be strongly influenced by what we observe today in the OECD countries. **But, once again, this does not mean that their energy demand per capita will be the same.** Differences in climatic conditions, in geography, in primary resources endowment, etc...will certainly result in strong differences in final energy requirement, as well as the tremendous possibilities of improving the efficiency in supplying the needs of energy services in the next hundred years.

In the industrialised countries of today, for which no reference exist as to the possible life-styles and consumption pattern in 2100, the growth in wealth and individual affluence is assumed to be used for three main purposes:

- pay for the increase in prices of goods and services coming from the rest of the world, resulting from the increase of the exchange rates of national currencies (against Euro, US\$ or Yen) in these countries;
- increase the standards of living of the fraction of the population with low income today in these countries (similar phenomenon as in developing countries)
- pay for new goods and services to be produced, in particular in the field of ICT's, leisure and tourism, and pay for the higher value of goods and services already available.

More needs of energy services per capita, but much less per unit of affluence

The overall needs of energy services of the world are calculated to be multiplied by 3.2 from 2000 and 2100 in the Mid-Pop scenario, while the world population would increase by 36%, the number of households would a little more than double and the global wealth would be multiplied by 8.

The needs per capita, which range roughly from 10 to 110 in the world in 2000, are calculated to be multiplied by 2.4 as a world average from 2000 to 2100, with a drastic reduction in the gap among world regions in 2100, between 35 and 140.

This brings a major shift in the world distribution of the needs of energy services, from the industrial world of today towards the developing world.

The needs of energy services per unit of wealth is calculated to decrease substantially, around -0.9% per year in average in the world. This is very close to the average decrease of the energy intensity of the GDP in industrialised countries during the 20th century¹⁹

Figure 39: Overall needs of energy services per capita (2000, 2100)

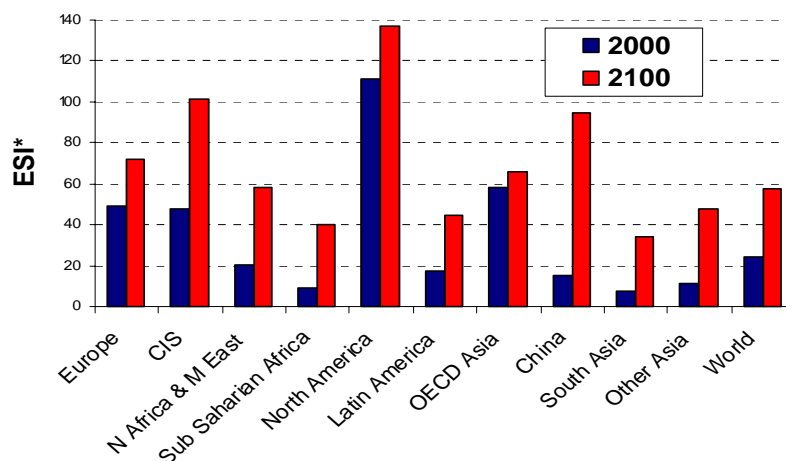
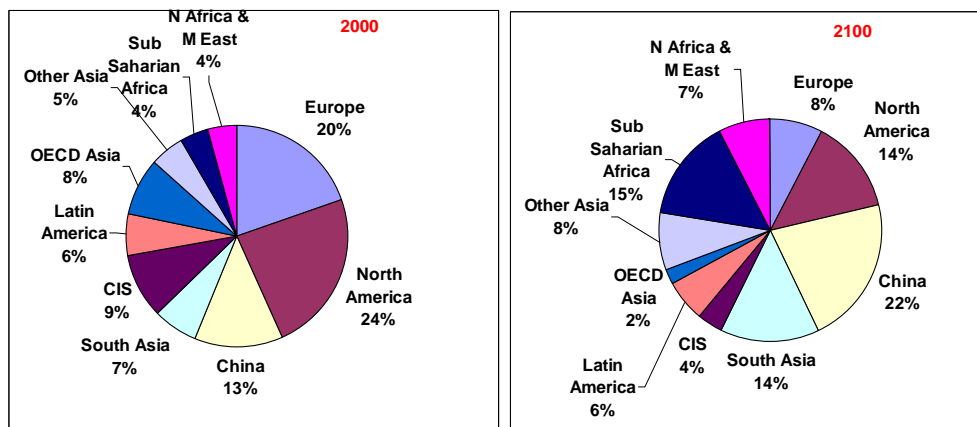


Figure 40: Distribution of overall needs of energy services per world region (2000, 2100)



¹⁹ the calculation on the 20th century is based on Enerdata’s long time series for energy, and estimates of GDP since the 19th century by [A. Maddison].

High exergy takes the bulk of the increase of the needs of energy services worldwide

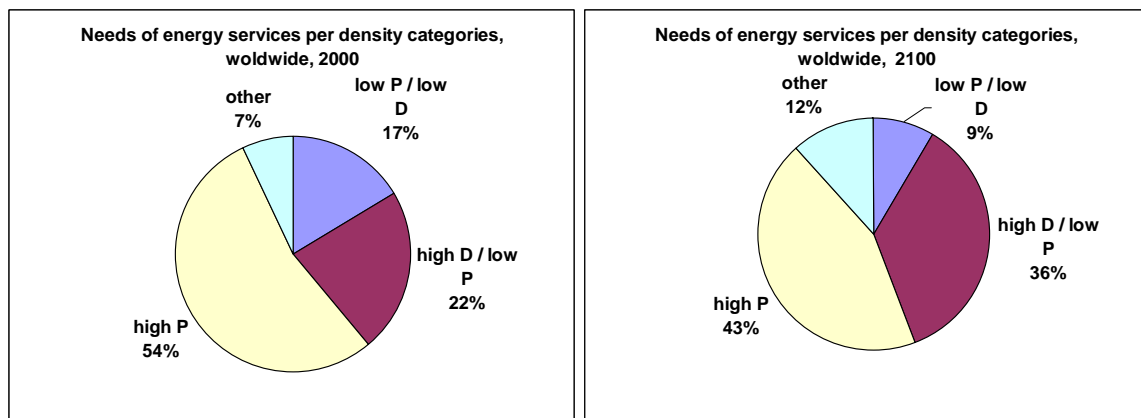
The share of the high exergy needs is calculated to increase drastically worldwide in the Mid-Pop scenario: from 14% to 24% for mobile high exergy (mostly mobility), and from 26% to 41% for stationary high exergy (mostly mechanical power and electricity devices). Conversely, the share of the low exergy needs (low temperature heat) is expected to decline from 14% to 9%, and that of medium exergy (mostly industrial heat), from 46% to 26%.

This structural change in the quality of the needs of energy services will have obvious impacts on the required quality of the energy carriers in 2100 as compared to today. In particular electricity is likely to play a much more important role than today, either through centralised transport/distribution systems or through distributed generation.

Towards more diffuse needs of energy services

One of the important characteristics of the evolution of the needs of energy services worldwide is the increasing share of the low unit power needs: from 39% to 47% of total needs between 2000 and 2100, at the expense of high unit power needs (whose share declines from 54% to 43%). This evolution gives a larger space for diffuse energy solutions and decentralised energy systems, and reduces the necessary requirement to centralised solution. Another important feature is the drastic reduction of the share of low density / low unit power needs. As a matter of fact, these needs are the most costly to supply from centralised energy systems: this evolution may result both in better economic performances of centralised systems, along with more opportunities for decentralised solutions

Figure 41: Distribution of overall needs of energy services per density/unit power categories (2000, 2100)



2.3.2 A first source of uncertainty: the role of women in the society

Women emancipation, a fundamental assumption

The fundamental assumption in VLEEM-BASES structure, as well as in the Mid-pop scenario, is that the women emancipation is an unavoidable phenomenon worldwide in any sustainable vision of the very long term. This assumption has eventually led to a final formalisation of VLEEM-BASES in which there is no gender specification, although this has

been partially developed and tested. In particular, there is no formal barrier in the model for women to access any education level and any paid job.

In the Mid-Pop scenario, this fundamental assumption has led to adopt specific consecutive assumptions on various topics:

- expected fertility profiles across time have been taken similar to those experienced in countries where the women emancipation is now a full reality
- enrolment in secondary and tertiary education is only limited by economic constraints, not by gender consideration
- participation in the labour market of the age class below the retirement is only determined by the education level, not by gender consideration
- no gender consideration in time-budgets evolution.

The uncertainty around this question is not really about the universality of the phenomenon during the next 100 years, but on the speed and the ultimate consequences of the phenomenon.

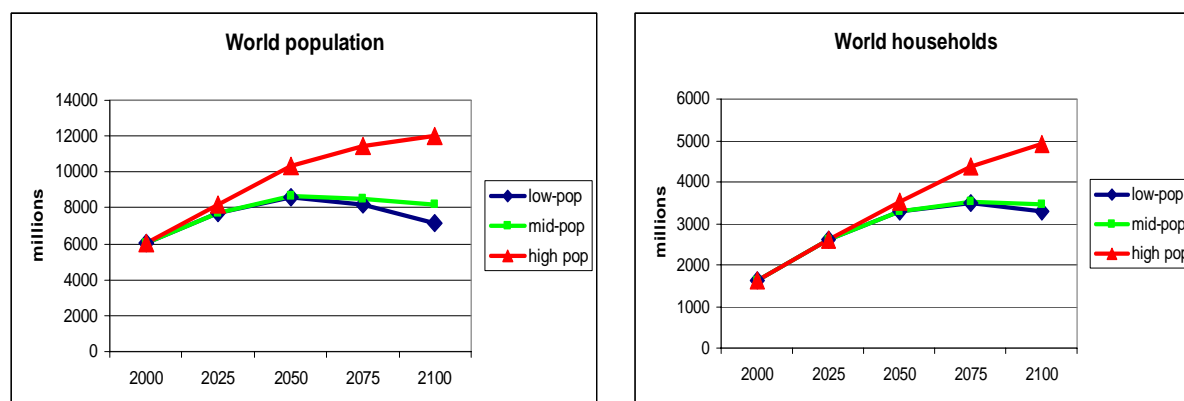
In the one side, one has to consider that women emancipation, at least in the sense given above, conflicts today with cultural and religious values, and with socio-political systems, in a number of countries around the world. Assuming the women emancipation in these countries means at the same time assuming that cultural and religious values will change, as well as the structures of the socio-political system. As indicated in the High-Pop scenario storyline, these changes could well be much slower than expected in the Mid-Pop scenario, and lead to a rather different vision in 2100.

In the other side, it is not clear today to which extent women emancipation can conflict with fertility in countries where emancipation is fully accomplished. To which extent women will give priority to their professional career, at the expense of family life or motherhood? Very contrasted situations exist today among advanced industrialised countries, where fertility ratios range from 1 to 2.5. Although we have considered in the Mid-Pop scenario that some stability in the world population should dominate after 2050 (as in the UN medium forecast, which implies that fertility ratios increase again everywhere after the historic decline), more drastic situations cannot be excluded, where fertility does not really resumes after the historical lower point. This also would lead to a rather different vision in 2100, as described in the story-line of the Low-Pop scenario.

What impacts of different fertility profiles?

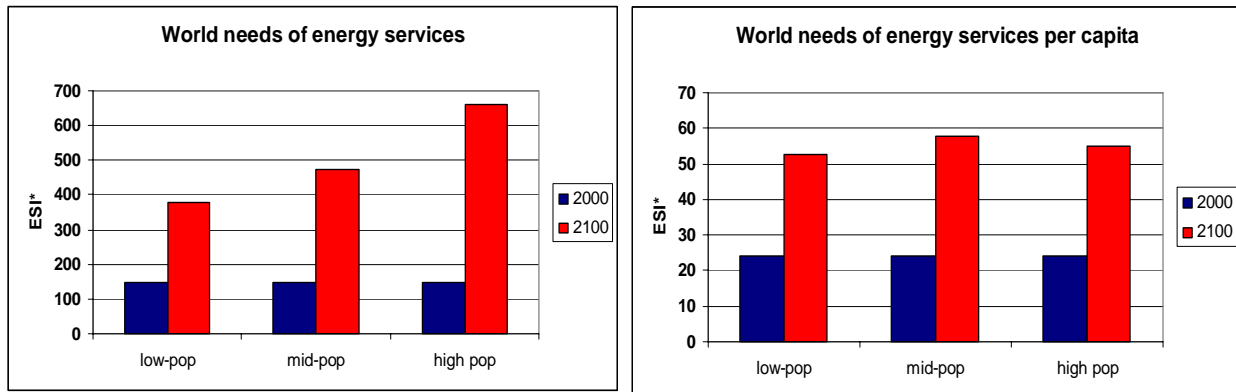
The uncertainty on the world population resulting from the possible speed and magnitude of the so-called demographic transition is between 7 and 12 billions people in 2100, and between 3.3 and 4.9 billions households.

Figure 42: World population and households in the three scenarios (2000, 2100)



Because of the less participation of women in education and paid jobs, and despite a more favourable overall demographic structure as regard the ratio active/non active people, the increase of individual affluence is calculated to be slightly less in the High-Pop scenario as compared to the Mid-Pop. One of the consequence is a slightly lower needs of energy services per capita in 2100. But altogether, a delayed demographic transition could result in a level of needs of energy services almost 40% above those of the Mid-Pop scenario in 2100.

Figure 43: World needs of energy services in the three scenarios (2000, 2100)



2.3.3 A second source of uncertainty: the time-budget for paid jobs versus self-accomplishment

Time for self accomplishment substitutes for time for paid jobs, a fundamental assumption in VLEEM

The fundamental assumption in VLEEM-BASES structure, as well as in the Mid-pop scenario, is that the trade-off between the time-budget allocated to leisure and retirement versus paid labour does not jeopardize the global financial balance between savings and financial capital requirements for investment in the production system. This means first that savings are supposed to match financial capital requirement at every moment worldwide, second that, whatever the savings requirement, consumption adapt through new equilibria between the utility of the marginal hour spent in consumption activities and the net revenue of the marginal hour spent at work.

The more the people work, the more money they get, the higher the economic growth and the financial capital requirement, the higher the savings needed, but the less time for consumption opportunities²⁰; and therefore the higher the value of the time for consumption opportunities compared to the value of time at work, and finally the higher the pressure to reduce working time. Different global equilibria are therefore possible, depending on the marginal value of time spent in leisure and in retirement as compared to the marginal salary.

In the Mid-Pop scenario, we have assumed that for all world regions, the overall trend for the coming century will be in the continuation of what has been observed in the industrialised

²⁰ See [Becker]

countries of today during the 20th century: the marginal value of the time for self-accomplishment increases faster than the marginal revenue from time spent at work, inducing a continuous substitution of time for self –accomplishment, for time at work. As shown above (fig 15), this leads to an average working time of around 1500 hours/year, and a retirement at 65.

The uncertainty around this question is twofold:

- in order to maintain a minimum economic growth, governments and enterprises' share-holders may force people to work more than they would like, i.e. beyond the equilibrium point where the marginal utilities equalize;
- disequilibria in the population structure by age in favour of old people may result in high financial transfers from active to inactive people that could jeopardize the global savings/investment and consumption/production equilibria, unless active people work more.

What impacts of higher working time?

At present, the model is not yet fully calibrated to account comprehensively for this issue: only the direct impacts through affluence increase and reduced time for in-door self accomplishment can be calculated. But one can expect also, for example, significant impacts through reduced time for out-door self-accomplishment, in particular in tourism, that the assumption of a constant time-budget for mobility does not allow to account for (at least directly): most likely, the disequilibrium in the marginal values of time spent in tourism and at work would result in an increased fractionality of tourism trips (escapades) combined with a more frequent use of airplanes for shorter vacation periods in resorts with high satisfaction level.

2.3.4 A third main source of uncertainty: social and geo-politic “viscosities”

Globalisation and global village, core assumptions in VLEEM

The fundamental assumption in VLEEM-BASES structure, as well as in the Mid-pop scenario, is that goods and services, people and financial capital circulate without restrictions among all countries of the world, and that all countries follow a similar welfare development pattern. This is embodied in the model structure, since the same set of behavioural relations are used for all world regions. This is also part of the Mid-Pop scenario storyline, which assumes convergence phenomena in life-styles, consumption pattern and technology specifications worldwide.

In the Mid-Pop scenario, we have assumed that the development pattern experienced by industrialised countries of today is replicable to developing countries of today, in particular as regard

- the global relations between demography, education, information, time-use structure and wealth
- the relation between time-use, information and affluence in the one side, needs of energy services in the other side.

The European model has been taken as a reference for similar regions of the world in terms of population density, size and diversity of member countries. The US model has been taken as a reference for the CIS and China (regions with low population density, large size and one country dominating).

There are uncertainties of different natures around these basic assumptions.

First, the industrialised countries of today have built their development in particular thanks to the exploitation of the natural resources of the developing world, that the developing world of today has very little chance to experiment in the future.²¹ This could jeopardize the necessary accumulation of physical capital in many countries because they will have to pay a much higher price for the necessary natural resources (relatively to the price system in the country) as compared to what was the case for industrialised countries of today.

Second, life-styles and consumption pattern of industrialised countries of today have cultural and religious roots often very different to what exist today in the developing world. These differences could (will?) result in hard conflicts in the developing world, between people more attached to their roots and people more “westernised”, and it is not sure that these conflicts would necessarily turn to the advantage of the seconds (as assumed in the Mid-Pop storyline). This may have consequences well beyond what has been investigated above concerning the women emancipation.

Third, there is a relation between the life-styles and consumption pattern in industrialised of today and the fact that labour costs are much lower in many parts of the developing world. This situation, most likely, will never exist for a large part of the developing countries of today; this means that the cost of these “western” life-styles and consumption pattern relatively to the hourly salary will always be higher for these developing countries than it is for industrialised countries today.

Last, it is questionable whether ores and natural resources availability worldwide would ever be sufficient to accommodate the equipment and consumer goods corresponding to the “western” life-styles and consumption pattern of today for 8 billions people.

What impacts of social and geo-political “viscosities”?

Accounting for these social and geo-political “viscosities” could have two major impacts as regard the results of the Mid-Pop scenario, beyond what has been investigated in relation to women emancipation.

The first impact could be some kind of polarisation of the population of the world regions in two main groups: those having adopted the “western” values, fully integrated in the world economy, and those rejecting the “western” values or unable to afford the corresponding life-styles and consumption pattern. Such a “two-speed” development would result in a reduced growth of the high education level people at work, a slower growth of labour productivity, a slower growth of the overall wealth, and increasing inequalities in the distribution of wealth²².

The second impact could be through increasing barriers to international trade and financial flows, because increasing social unrest in developing countries and political suspicion between rich and poor countries. This would threaten or delay the capital stock building in developing countries, make the increasing deficit between savings and financial capital requirement more difficult to finance in ageing industrialised countries, and make the competition among world regions for natural resources more tough. All these consequences would impact negatively the economic growth in all countries, and could force the richer countries to try to attract more and more high educated people from the developing world to counter-balance the negative effects on the economic growth, with a further negative impacts on the developing world, amplifying the discrepancies in affluence between rich and poor countries.

²¹ See P. Jallet, “Le pillage du tiers-monde”

²² This is close to Shell’s scenario “ “

3. Chapter 3: From Energy Related Needs to Final Energy Demand: Options for End-Use Technologies and Energy Efficiency Possibilities

A myriad of technologies is being used to satisfy the various physical needs of society. Depending on the concrete case, the stage of science and technology and the technological environment numerous technological options sometimes co-exist over longer periods of time, hence leading to technological diversity, while in other cases, a certain technology prevails at least for a certain period after which it may be replaced by another technological solution. An example for the first category is the production of domestic hot water in oil, gas and electric boilers. Examples for the second category are the steam engine as a source of power for trains and industrial production in the Western hemisphere during most of the 19th century and the use of internal combustion engines in cars in the 20th century and today.

The lifetime of technological options can differ substantially depending on the service provided and the type of the artefact. For example, the use of packaging is usually limited to a few weeks, while durable consumer products (furniture and cars) are typically used for one to two decades and the built infrastructure such as buildings and infrastructure as roads and railway tracks have a lifetime of around one century. Any man-made product can theoretically be replaced at any time but the costs and other accompanying societal burdens generally prohibit a very rapid turnover. As a consequence, especially long-lived artefacts are the reason for the slow transition to a more sustainable economy. Figure 44 shows the example of the stock of floor space in dwellings in Europe (33 countries) as a function of the demolition rate which is currently estimated at around XXX% (REF). While for long-lived products such as buildings technological innovations are typically delayed, retrofit measures may, on the other hand, be taken (e.g. heat insulation of old houses or revamping of industrial plants). Such retrofit measures typically also involve technological innovations and represent a key strategy for long-lived artefacts. Nevertheless, the degree of freedom generally decreases with increasing industrialization and development. This is also true for decisions taken in the 21st century: Depending on the concrete case, decisions taken in the first two centuries determine, to a considerable extent, the decision space in later centuries. Setting out with a huge degree of freedom we have today, (nearly) every decision taken now narrows down the degree of freedom for decisions to be taken at later stages.

In the next sections, the production of bulk materials (Section 3.1), mobility and transportation (3.2), households (3.3) and services and small consumers (3.4) are discussed. The activity levels in these sectors are related to population, education and time budgets. For most sectors, the activity levels have been discussed in detail in Chapter 2, with bulk materials being an exception and therefore being covered here (Section 3.1).

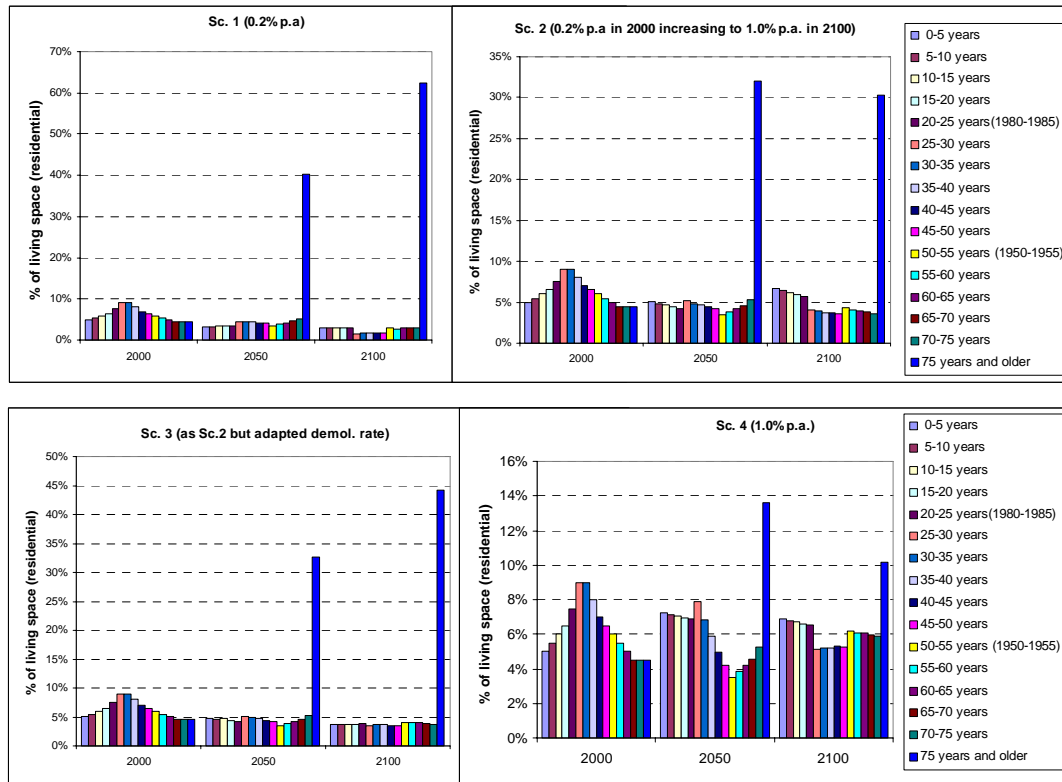


Figure 44: Age composition of dwellings in Europe as a function of the demolition rate

3.1 Production of bulk materials

The two major drivers for energy use related to the production of bulk materials are the production volume and the specific energy needed to produce one tonne of a given material (the so-called SEC, specific energy consumption). The materials contributing most to global energy use have been taken into account; these are - in order of decreasing (primary) energy use – polymers, iron and steel, paper, cement, aluminium, ammonia, wood, bricks & tiles and glass.

3.1.1 Projections for material production

The projections for the future demand for materials are based on an historical analysis of consumption patterns for various materials. By plotting material consumption per capita as a function of per capita GDP for as many countries and years as possible representative relationships between affluence (wealth) and material use were established (see example for paper in Figure 45).

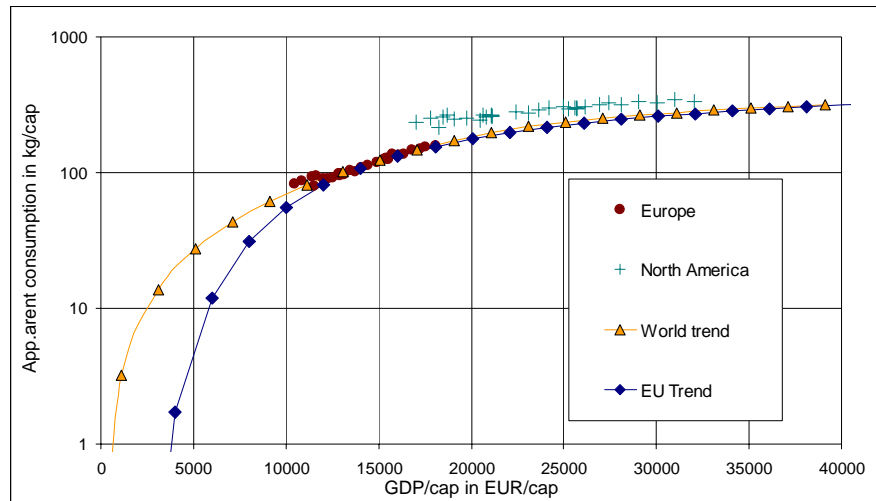


Figure 45: Per capita apparent paper consumption versus per capita income for paper

The fitted curve of the type shown in Figure 45 have been combined with projections for gross domestic product (GDP) and population according to chapter 2 to generate projections for the future consumption of materials. For countries that nowadays have relatively low levels of material use this curve can be used directly for projections (because the relationships for high-income countries can be made use of) while, for high-income countries, the fitted curve first needs to be projected. This approach assumes that no trend breaks in consumption patterns occur in future and hence leads to projections which can be described as business-as-usual.

Between year 2000 and 2100, total material use is projected to increase by 70% or 0.53% p.a. in Europe (EUR-33) and by 380% or 1.6% p.a. in the rest of the world (Figure 46). In both world regions, plastics are projected to grow fastest, followed by aluminium (in particular, secondary aluminium) and glass. The materials with the lowest growth rates in both regions are ammonia, bricks/tiles and cement. As shown in Figure 47, material use is projected to increase most rapidly in South Asia and Sub-Saharan Africa: between 2000 and 2100 by around 3000 million tonnes in both regions, i.e., approximately 3.5-fold of today's total material production in Europe (870 million tonnes) and around 3% p.a. and around 4% p.a. respectively. The region Other Asia Pacific is third in terms of growth rates and fourth in terms of growth in absolute terms. China takes the third position in terms of growth in absolute terms while having the lowest growth rate of all developing regions (somewhat less than 1.0% p.a.). Absolute growth in the remaining developing regions – i.e., North Africa/Middle East and Latin America – is substantial (around 1 000 million tonnes), with average growth rates of 2.3% p.a. and 1.6% p.a. respectively. Material production in industrialized countries grows by 0.5% p.a. (Europe), 0.7% p.a. (North America) and to 0.8% p.a. (Former USSR) with a decline in production being expected only for Asia Pacific OECD (-0.2% p.a.).

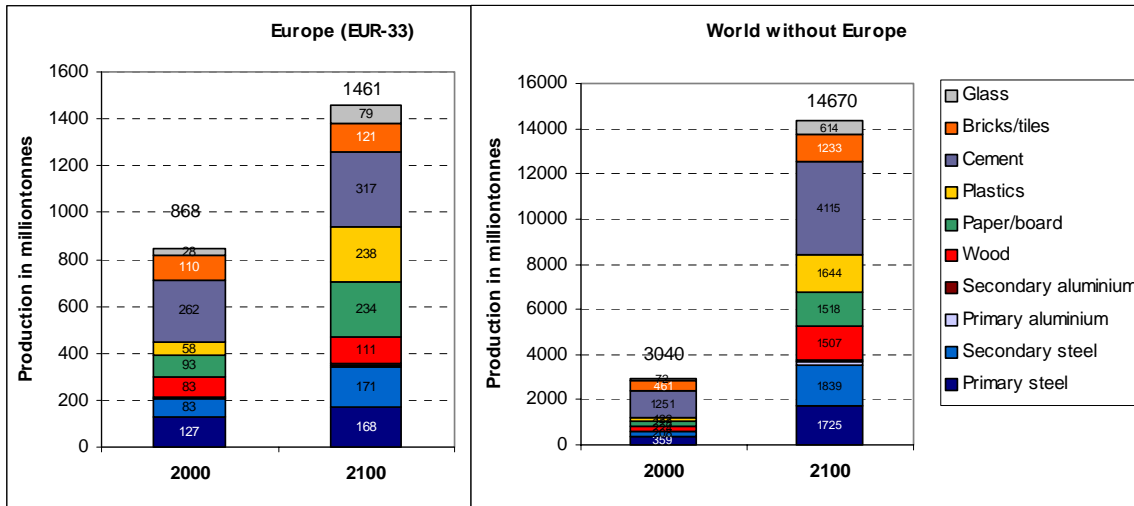


Figure 46: Current and future use of materials (MidPop scenario) for Europe (EUR 33, left) and the rest of the world (total world without Europe) according to a business-as-usual scenario

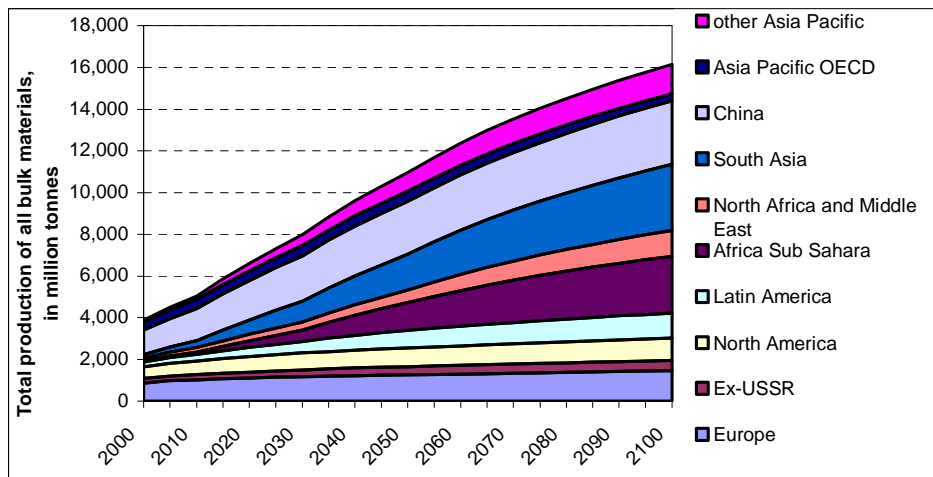


Figure 47: Projected production of the total of all eight bulk materials by world region

3.1.2 Energy efficiency and fuel options

While the level of material use is determined by population, wealth and consumption patterns, the level of energy efficiency is a consequence of the technology used. To make projections for future specific energy consumption (SEC), we first made an inventory of results from studies on energy efficiency potentials. We focus here on the use of non-renewable energy. Most relevant studies cover time periods until 2020 up to 2050. Beyond this point of time, it

is hardly possible to estimate the specific energy consumption on technological grounds. The specific energy use for the remaining period until 2100 has been projected by extrapolation, thereby taking into account the limitations of thermodynamics. Using this approach it has been projected that around one half (e.g. for secondary aluminium, primary aluminium and secondary steel) to three quarters (e.g. for bricks/tiles and cement) of the today's gap to the thermodynamic minimum will be bridged by 2100. The expectable progress depends on the current state of technology and foreseeable innovations and it differs considerably as shown in Figure 48.²³

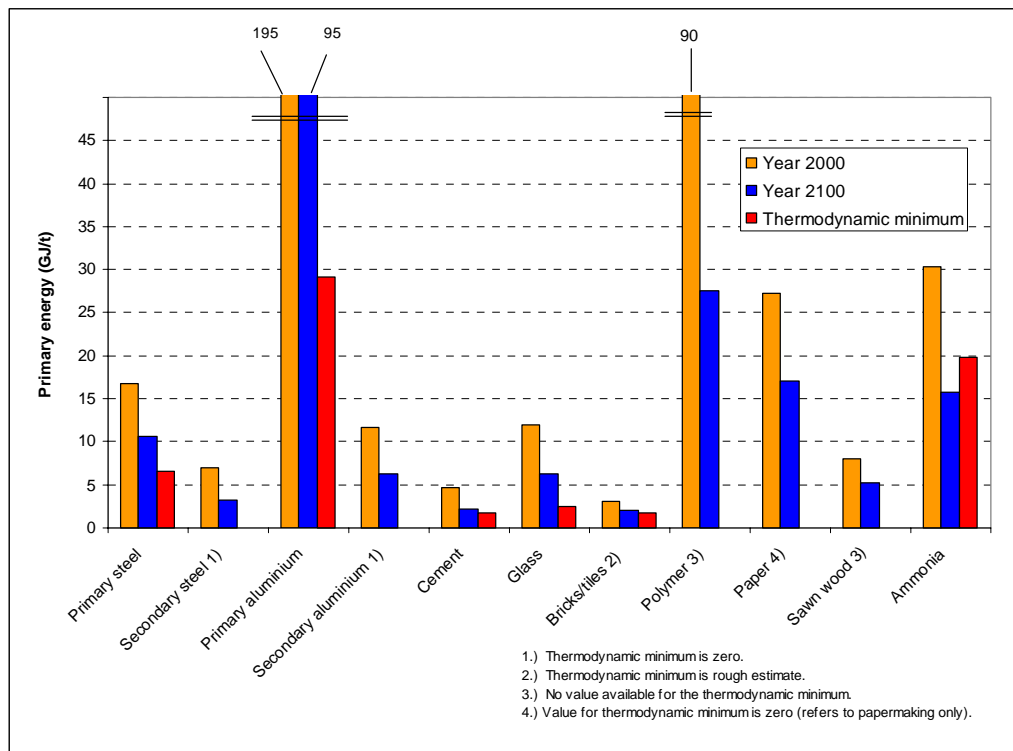


Figure 48: Energy use (in primary energy terms) for the manufacture of bulk materials in year 2000, 2100 and for the thermodynamic minimum

A summary of current and future specific energy use (SEC, in primary energy terms) is shown in Table 3-1. Energy efficiency in the year 2000 is substantially higher in developing countries compared to industrialized countries for primary and secondary steel and secondary aluminium while it has been estimated to be around 20% higher for all other materials (the real SEC values may differ from this default value but cannot be retrieved from publicly available sources). For the year 2100, the gap for specific energy use between industrialized and developing countries is projected to decrease to around 5-10% for most materials. Important exceptions are plastics and ammonia where far-reaching technological breakthroughs have been assumed for industrialized countries (see below for further explanations). Given the continued internationalization of production, it may, however, occur

²³ Energy use in Figure 48 is expressed in terms of primary energy in order to account for the conversion efficiencies for generating power and heat. Efficiencies of 33% for power and of 90% for steam have been assumed for this purpose. While this allows first comparisons across technologies on the energy demand side the integration with the energy supply side (as discussed in Chapter 4) requires scenario-specific adaptations.

that the SEC values for some materials will be lower in (certain) developing countries than in industrialized countries; an example could be the large-scale and highly advanced production of bio-based plastics in countries such as Brazil with ample availability of low-cost biofeedstocks. The data displayed in Table 3-1 should therefore be considered as first approximation that should be adapted in future studies if sufficiently reliable information becomes available at the level of countries. Background information on the estimates shown in Table 3-1 is provided below by type of material.

Specific energy use (SEC) in primary energy terms, in GJ/t	Industrialized countries		Developing countries	
	2000	2100	2000	2100
Steel				
- Primary steel	16.8	10.6	35.3	11.4
- Secondary steel	7.1	3.2	16.5	3.8
Aluminium				
- Primary aluminium	195	95.8	234	109
- Secondary aluminium	11.6	6.3	20.0	7.6
Cement	4.7	2.2	5.6	2.4
Glass	11.9	6.3	14.3	7.0
Bricks/tiles	3.0	1.9	4.0	1.9
Plastics	90.0	27.5	110	40
Paper	27.3	17.0	32.8	17.8
Wood	8.0	5.2	9.6	5.6
Ammonia	30.3	15.7	36.4	23.9

Table 3-1: Overview of average current and future specific energy use (SEC) for bulk material production in industrialized and in developing countries (the data represent non-renewable energy use and are given in primary energy terms; see footnote on preceding page for explanation)

Steel

Steel can either be produced from iron ore or from steel scrap. Steel produced from iron ore is also referred to as primary steel, virgin steel or BOF steel (BOF stands for Basic Oxygen Furnace). Steel produced from steel scrap is recycled steel and is also referred to as secondary steel, electric steel or EAF steel because it is produced in electric arc furnaces (EAF). As shown in Figure 3-3 both primary and secondary steel will be required by the end of the century. The production of secondary steel, which is much more energy efficient to produce than primary steel (see Table 3-1), is determined by the availability of steel scrap. Industrialized countries with a mature infrastructure generate larger quantities of steel scrap than developing countries. While steel scrap is traded world-wide, the larger availability in industrialized countries is likely to lead to a higher share of secondary steel compared to the developing world also in the long term (compare Figure 3-3). Secondary steel currently accounts for around 40% in Europe and for somewhat less worldwide (approx. 37%). Concerning technical feasibility, there is still ample room for increasing the share of secondary steel since, according to steel industry, 80% of the total range of all steel products produced could be made by recycling of steel scrap (Charbonnier et al., 1999, p.7).

Primary steel is mainly produced via blast furnaces but an increasing share is being made by means of direct reduction (today approx. 15% worldwide) and – to a lower extent – by smelt reduction. Blast furnaces require the use of coke and coal, i.e. of fuels with high carbon content. In contrast, commercialized direct reduction processes nowadays use natural

gas derived mixtures of hydrogen (H₂) and carbon monoxide (CO) with a ratio of 1 to 1.5 (Midrex process; see Tacke and Steffen, 2004). These processes are capable of reducing iron ore with any combination of H₂ and CO and hence offer the possibility of a gradual transition to a hydrogen economy. This might even be accompanied by efficiency gains because, at temperatures beyond 850°C, hydrogen has a stronger reducing power than CO (Tacke and Steffen, 2004).

The development of specific energy use (SEC) for steel according to Table 3-1 (40%-50% savings between 2000 and 2100) implies that around 60% of the gap to the thermodynamic minimum will be closed by 2100. This substantial energy savings are expected in view of the possibilities identified for the short term, which include also the production of blended cement (IEA GHG Programme – Cement, YEAR).

Accurate energy comparisons for materials need to account for all direct and indirect process inputs. For the blast furnace route this involves, in particular coke which needs to be produced in coke ovens. For direct reduced iron, further processing in electric arc furnaces is required. The energy use for this step is higher than for a conventional electric arc furnace (EAF). In total, blast furnace route is currently around 2 GJ/t more efficient. We hence assume that further developments in technology and scale will make the DRI route comparable to the blast furnace route in terms of energy use and we therefore do not distinguish between the two routes. Assuming the growth and process shares shown in Figure 3-3 and progress in energy efficiency according to Table 3-1, total energy use for steel (which nowadays belongs to the top 3 products in terms of energy use next to polymers and paper) is expected to remain at similar levels in industrialized countries while increasing manifold in developing regions.

Aluminium

As is the case for steel, aluminium can either be produced from bauxite (primary aluminium) or from scrap (secondary aluminium). Primary aluminium, which is produced in an electrolysis process, is by one order of magnitude more energy intensive to make than the smelting process leading to secondary aluminium (see Table 3-1). As for steel, the volume of secondary aluminium is limited by the availability of aluminium scrap. Among all major bulk materials, primary aluminium is most energy intensive to produce, while the specific energy use for the production of secondary aluminium is similar to that of glass and somewhat higher than that of secondary steel (see Table 3-1). World-wide primary aluminium accounts for only around 5% of the volume of primary steel and the respective ratio for secondary steel is even only around 2.5% (the quantities are therefore hardly visible in Figure 3-3). In absolute terms, the energy use for secondary aluminium production is therefore practically negligible while that of primary aluminium is equivalent to one third (Europe) to half (world) of the energy use for primary steel (energy values in primary energy terms). Since aluminium is a rather young material, its growth is likely to outpace that of primary steel for a longer period of time and as a consequence, the energy use (in primary energy terms) for its manufacture may come rather close to that of primary steel in the long run.

The development of specific energy use (SEC) for aluminium according to Table 3-1 (approximately 50% savings for both primary and secondary aluminium between 2000 and 2100) implies that 50%-60% of today's gap to the thermodynamic minimum will be closed by 2100 (both for primary and secondary aluminium).

Cement

While not being energy intensive to produce (lowest specific energy demand of all bulk materials shown in Table 3-1) cement is by far the most important material in terms of production volume (both in 2000 and most likely also in 2100). For example, by the year 2000 global cement production was around twice as high as primary steel production and accounted alone for around 40% of the total production volume of all bulk materials studied here (compare Figure 3-3). This explains why the energy in absolute terms (in primary energy equivalents) is worldwide rather close to that of primary steel.

The development of specific energy use (SEC) for cement according to Table 3-1 (approximately 50% savings between 2000 and 2100) implies that more than three quarters of the gap to the thermodynamic minimum will be closed by 2100. Energy savings of this extent are projected in view of the possibilities identified for the short term, which include also the production of blended cement (IEA GHG Programme – Cement, YEAR).

Glass

Glass belongs to the small materials in terms of production volumes. The specific energy use for production falls into the lower medium range. In terms of absolute energy use it therefore plays a rather subordinate role.

The development of specific energy use (SEC) for glass according to Table 3-1 (approximately 50% savings between 2000 and 2100) implies that around 60% of the gap to the thermodynamic minimum will be closed by 2100.

Bricks and tiles

In Europe and also world-wide, bricks and tiles nowadays represent the third largest product group after cement and steel. It is expected that they will have been overtaken by paper and plastics by the end of the 21st century. The average energy use for the production of bricks and tiles is lowest of all materials studied (see Table 3-1). In absolute terms, energy use for the manufacture of bricks and tiles is medium to low, with decreasing relative importance for the future.

The development of specific energy use (SEC) for bricks and tiles according to Table 3-1 (approximately 40% savings between 2000 and 2100) implies that around three quarters of the gap to the thermodynamic minimum will be closed by 2100.

Polymers

Polymers are sixth in production volumes in Europe nowadays (after cement, steel, bricks/tiles, wood and paper) but they are projected to climb up to the third position by the end of the 21st century (after cement and steel; compare Figure 3-3). Due to the high specific energy use for polymer production (second after primary aluminium, see Table 3-1), energy use in absolute terms (including feedstocks) is by far the largest of all bulk materials: It is around twice as high as the total energy use for the production of both crude steel (including both primary and secondary steel) and paper, which stand at similar levels (valid for both Europe and the world; all data represent non-energy use and refer to energy in primary energy terms).

The development of specific energy use (SEC) for polymers according to Table 3-1 (approximately 70% savings between 2000 and 2100) is thermodynamically impossible if current technology is applied. Such low energy requirements can only be reached under the precondition of successful development and large-scale implementation of bio-based processes that make use of renewable resources as feedstocks (note that the data in Table 3-1 refer to *non*-renewable energy). Among the bio-based processes, two major processing routes can be distinguished, i.e. biotechnological processes and thermochemical processes (such as pyrolysis or syngas-based routes). Food crops such as maize, wheat, sugar cane and vegetable oils will probably be used in initial phases of setting up biotechnological processes but they will be increasingly replaced by woody biomass (lignocellulosics) which are also the preferred feedstock for thermochemical routes. In spite of the optimistic assumptions made in Table 3-1 for the transition to bio-based polymers, the contribution of polymers to total energy use (in absolute terms) is very likely to increase due to the substantial increase in production.

Paper

Paper is made from a renewable resource (wood) but nevertheless non-renewable energy is required (in addition to the energy produced from fuel-grade byproducts originating from the renewable feedstock, in particular black liquor). The SEC values for paper displayed in Table 3-1 are relatively uncertain due to the large number of paper grades (including recycled paper) which differ substantially in energy use and for which the mix across countries and regions also varies. In spite of these uncertainties it is safe to say that paper is energy intensive to produce and is nowadays responsible for a total energy use (in primary energy terms) that similar to that of crude steel.

Total future energy use will depend not only on the future level of specific energy use (approx. -35% acc. to Table 3-1) but also on the absolute level of production which is projected to increase substantially (by a factor of 2.5 in Europe between 2000 and 2100; see Figure 3-3) and by even more than twice as much worldwide. As for all other materials the actual value will depend, among other factors, on the competitiveness relative to other materials. In particular, the introduction of “electronic paper” (e.g. for newspapers) might lead to a trend break which is not captured in the business-as-usual trajectory for material demand (Figure 3-3).

Wood

Wood is referred to here as construction material and excludes the quantities required for paper production and, in the longer term future, possibly also for polymers and other chemicals (see above). As for paper, non-renewable energy is required to process wood in addition to the use of renewables in the form of waste for energy purposes. The specific energy consumption is relatively low (see Table 3-1). The total production of wood products is nowadays similar to that of paper or secondary steel. It is expected to increase only slowly in industrialized countries while the production of (final) wood products in developing countries may increase as a consequence of rapidly rising domestic demand (see Figure 3-3 for Europe).

Ammonia

Ammonia is nowadays exclusively produced from fossil resources (predominantly natural gas), involving energy intensive syngas production and high-pressure synthesis. Apart from further optimization of the conventional process which allows further reduction of energy use especially in the developing world, major improvements can only be reached by major technological breakthroughs such as the production of ammonia or ammonia-containing compounds by means of biotechnology (symbiosis between micro-organisms and crops, genetically modified crops with the ability of nitrogen fixation or crops or other biotech systems leading to nitrogen-rich compounds for subsequent separation²⁴).

The projected development of specific energy use (SEC) for ammonia according to Table 3-1 (approximately 50% savings between 2000 and 2100) is thermodynamically impossible if current technology is applied; such low energy requirements can only be reached if biotechnological processes can be developed that make use of renewable resources (the data in Table 3-1 refer to non-renewable energy).

Summary for bulk materials

A limited number of bulk materials are responsible for a considerable amount of energy use because they are either energy-intensive to produce (high SEC values), are produced in very large quantities, or both. In Europe, polymers, steel and paper alone currently account for nearly three quarters (with cement: more than 80%) of the total energy use (in primary terms) required for the production of all bulk materials discussed above. Globally, the share is somewhat lower (two thirds for the total of polymers, steel and paper; three quarters including cement).

Specific energy consumption (SEC) for the very long-term future was established by combining insight gained from bottom-up technology studies (for the next 2 to 3 decades) with information on the thermodynamic minimum. The projections for specific and absolute energy use should be considered as rough first analyses which should be improved by future research. The key conclusions are:

- Substantial energy saving potentials exist for all bulk material, with SEC reduction potentials lying in the range of at least 30% up to 60% or even 80% in exceptionally promising cases.
- In general, these energy saving potentials are based on information on (rather) conventional processes and - due to lack of information - do not account for the effects of possible technological breakthroughs, e.g. in the field of nanotechnology. Accounting for these currently largely unforeseeable developments could lead to SEC projections that may be either higher or lower than in the present study.
- As an exception, technological breakthroughs have been assumed in the area of industrial biotechnology, leading to unprecedented energy savings especially in polymer production and for the production of ammonia.
- The methodology applied to project future material production and consumption is based on the continuation of the dynamics that have prevailed in the last decades and can hence be viewed as a business-as-usual trajectory.
- Combining the projections for production with those for the SEC values allows to summarize the results for the entire bulk materials sector:
 - The dividing the projected overall total energy use (in primary energy terms) for all bulk materials in Europe 2100 (16,010 PJ) by the total production of all bulk materials

²⁴ See [De Beer] p. 233

(1,475 million tonnes) gives a weighted overall specific energy consumption of 10.9 GJ/t as compared to a value of 16.5 GJ/t for the year 2000. This reduction in energy use is equivalent to a decrease by 0.41% p.a. on average.

- If, in contrast, no progress were made in terms of SEC values – i.e., in the case of a frozen efficiency scenario – the overall energy use (in primary energy terms) would increase to 26.2 GJ/t. This value is even higher than that for the year 2000 (16.5 GJ/t) due to the overproportionally large increase of energy intensive polymer production.
- As long as fuels are simply used for raising heat, fuel substitution towards hydrogen generally does not lead to problems. Cleaner fuels usually offer advantages in the process (e.g. for smelting glass). Direct substitution cannot be assumed in the case of fuels used as feedstocks where chemical reactions take place or mechanical requirements must be met. Two such cases can be distinguished:
 - It has been discussed above that the use of hydrocarbons is expected to decrease substantially in the case of polymers and ammonia by using biomass-derived products as feedstocks.
 - For the production of iron (for primary steel) in blast furnaces, carbonaceous feedstocks (especially coke) are indispensable. However, it is possible to produce iron by use of hydrogen only by shifting from the blast furnace process to direct reduction. In all other cases the transition from carbonaceous fuels to hydrogen does not require any specific process-related adaptations.
- The saving potentials identified will not occur as autonomous development. In contrast, to put them into industrial practice will require a major and sustained effort in governmental and industrial R&D and in industry transformation across the globe. This is obvious from the comparison of projected overall SEC value in 2100 (10.9 GJ/t) as compared to the frozen efficiency SEC in 2100 (26.2 GJ/t). This is equivalent to an energy efficiency improvement of nearly 0.9% p.a., sustained over 100 years.

3.2 Mobility and transportation

As discussed in Chapter 2 transportation services (passenger and freight) are projected to more than quintuple from 2000 to 2100 (see Chapter 2.2.4). Most of the growth will occur in developing countries which a projected increase of transportation services by a factor of 13 while transportation in industrialized countries is expected to increase by 2 between 2000 and 2100.

3.2.1 Energy efficiency and fuel options

Figure 49 shows the energy use of all major current transportation modes for passengers and freight. All these transportation modes are also considered relevant for the long-term future even though it is unknown today which concrete form they will take (e.g., new synergies between rail and cars). Totally new or revived transportation technologies such as Zeppelin systems for cargo are not specified but are considered to be rather close in energy efficiency to one of the other modes modelled (e.g. long-distance rail). Freight transportation by air is not depicted because most of the air cargo is transported in the belly of passenger airplanes and the respective energy use is hence included in the value for passenger transport by air. Moreover, 2- and 3-wheelers are not shown in the graph (due to their relatively low

contribution to overall energy use) but are taken into account in the model calculations. Soft modes such as walking or cycling are neither shown since they do not rely on non-renewable energy.

The fuel options foreseen for the long term are liquid hydrocarbons (e.g., in the form of gasoline, diesel and kerosene), hydrogen and electricity. Liquid hydrocarbons may originate from fossil fuels (oil, gas and also coal) or from biomass (e.g., vegetable oil, starch crops or wood). The various fuels are used in internal combustion engines (ICE), hybrid systems, fuel cells or gas turbines (especially for planes). Propagation based on electric power is also considered as long-term option in various forms (esp. for passenger cars and rail). Further fuels options such as methanol or compressed air are not explicitly included but lie within the range of fuel efficiency for the options that are taken into account in the model. Propagation systems that are nowadays not considered realistic for large-scale introduction in transportation - such as systems based on nuclear energy or on photovoltaics - are not included. This may lead to wrong conclusions if currently unexpected breakthroughs are reached.

The values shown in Figure 3-6 are expressed as final energy use since the energy efficiency and emissions for power and hydrogen production will depend decisively on the technology choices on the supply side and should hence be analysed from a systems perspective (see Chapter 4). Nevertheless it is interesting to compare end-use energy efficiencies. For the period 2000 to 2100, it is projected that energy efficiency can be increased by up to two thirds for passenger transport by car and by air, by up to somewhat more than half for public transportation on roads and by 15-35% for passenger transport by rail (different values for high speed, medium speed and local rail). For freight, energy efficiency can be increased by somewhat more than half for freight transportation by road, by 10-25% for rail and by around one third for freight transport via waterways and overseas.

While transportation technology can be assumed to be globally available due to trade of vehicles and rapid transfer of production systems, the specific energy use will differ by region for the following reasons: some regions with higher wealth change their car stock rather rapidly thereby moving quickly towards a high overall fuel efficiency of the total fleet while in other high-income regions affluence may (continue to) lead to overpowered vehicles with relatively high energy use. The opposite could be true for developing countries, leading partly to low efficiencies due to an aged stock while elsewhere lower affluence may lead to higher shares of fuel-efficient vehicles. In addition, differences in occupancy rates across the globe are likely to remain to some extent (the values in Figure 49 refer to energy use per person-km and tonne-km and are hence determined by multiplying vehicle efficiency with occupancy rate).

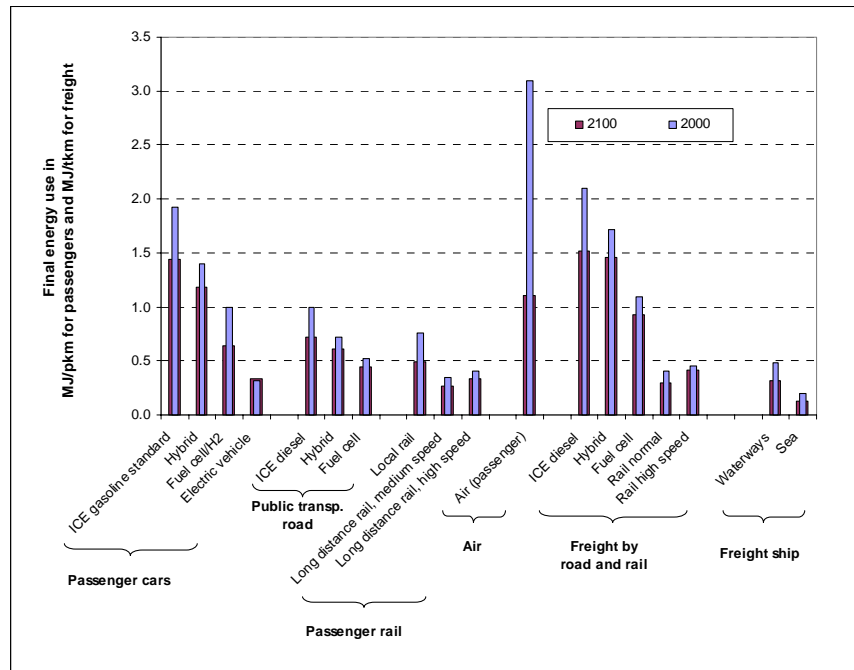


Figure 49: Overview of specific energy consumption for various transportation modes in Europe, 2000 and 2100

3.2.2 Fuel cells as key factor in the transportation system

The major part of current transportation relies on internal combustion engines (in Europe currently accounting for around 75% of the transportation energy without ships and around 85% with ships). As shown in Figure 49 the largest fuel efficiency gains are achieved by making the transition either to fuel cells or to electric vehicles. In both cases the well-to-wheel fuel efficiency in primary energy terms will depend on the efficiency of producing the combustible fuels (e.g. hydrogen) and electricity and therefore can only be discussed in an integrated assessment (see Chapter 4). Due to the outstanding importance of fuel cell technology in current governmental and corporate R&D this section discusses the application areas, the stage of development and timeframes of this technology. Breakthroughs in fuel cell technology dedicated to transportation would probably also be accompanied by increased application for combined heat and power in stationary applications.

Fuel Cell Technology as a future energy generation system

There is no doubt that the fuel cell technology is a very attractive energy conversion respectively useful energy generation technology which has a very high fuel-to-power efficiency as the process is not limited by the Carnot-Efficiency. A broad use of the fuel cells would open the opportunity to reduce in many applications the specific energy consumption

without turning down any comfort. If the fuel cell is fuelled with pure hydrogen, it emits no direct greenhouse gases and could therefore play an essential role in the achievement of a cleaner energy world (however, the indirect emissions from the reforming process have to be taken into account).

It is expected and hoped, that the fuel cell technology will be used in a variety of applications as indicated in Table 3-2.


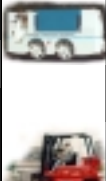

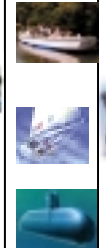



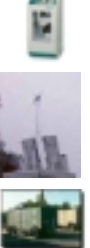

Application	Mobile						Stationary		
	drive			Power supply (APU)			Power and heat supply		
power	30 – 100 kW	>100 kW <100 kW	> 100 kW				1 – 50 kW	200 kW- some MW	
application	vehicle	utility vehicle & mobile machines	busses	ships sub-marines	space-shuttle	Trucks, motorhome utility vehicle etc.	planes, ships, mobile machines	residential, remote power etc.	distributed power supply
product (examples)									

Table 3-2: Examples for possible applications of fuel cells
 Source: AMCG-Unternehmensberatung GmbH

The requirements and conditions in the various applications differ widely. While for public or industrial stationary generation systems large operating times must be achieved (if possible 7,000 to 8,000 hours with insignificant load changes) only 260 yearly operating hours are reached in the transportation sector by passenger cars. Here, fuel cells must cope with the extremely quick load changes. Such a mode of operation is demanding not only for the fuel cell but also for the peripheral components. Unless hydrogen is the fuel stored in the vehicle these peripheral systems include the reformer system, in which hydrogen is generated from the fuel that is transported on board.

Small power plants with a capacity of less 100 kW to some 1,000 kW are categorised as stationary systems and used for the distributed public and/or industrial supply. This category includes also fuel cells for use in the residential sector where often thermal boilers and flow heaters are used for space heating and hot water. The typical capacity range of thermal boilers is ~14 kW_{th} for single family houses and ~ 7 kW_{th} for flats. This application has significantly different operating regimes than those for public or industrial use. The yearly operating time is normally less than 1,600 hours in climatic regions like Germany and with better isolation standards in the future the demand and operating times will be even lower. It should be noted here that the generation of heat is not the strength of the fuel cell. Its great advantage is the

efficient power generation at a range of up to 50 % or even 60 % electrical efficiency based on the lower heating value of the fuel.

Due to the insufficient speed of the response of the periphery components at changing load the fuel cell systems are not predestined to follow fast load changes and therefore they are not well suitable to generate electricity corresponding to the electrical load curve of a typical household or the demand curve of a passenger car during the acceleration phase. The energy amount, which cannot be delivered by the fuel cell (due to the gap between maximum capacity and demand) must be made available from a backup system. For the automotive application, suitable battery systems are under development and for the households the public electricity grid is such a supply source.

Stage of development

In this section the technological status of the fuel cells is described at the example Germany, where a couple of companies is developing systems for both stationary and mobile applications.

The funding of the German government concentrates on the one hand on systems for the residential market because this would enable large energy saving potentials within the existing building stock. The development of small units of the high temperature fuel cell type as well as of the low temperature fuel cells started a couple of years ago but because of various problems concerning materials and/or components it has not yet been completed and the manufacturers cannot yet present systems which could be considered as being advanced prototypes. Partly the technical problems encountered were so serious that new system developments became necessary. In general, the companies developing fuel cell systems expect pre-commercial units to be available in the time range of 2006 to 2009.

The development of the high temperature Molten Carbonate Fuel Cell of the company MTU seems to be very advanced and close to market introduction. Its focus are those applications, where also heat can be used either for district heating, for steam generation in industrial production processes or for sterilisation as it is done in hospitals. At present the manufacturing costs are still in the range of 10,000 Euro/kW_{el}, but MTU hopes to scale down that range to 1,500 Euro/kW_{el} within the next 10 years to become competitive to other conventional and innovative technologies.

Company reports on research, development and progress in the field of fuel cell systems indicate that there are a couple of unresolved technical problems, making it rather unlikely that fuel cells will be introduced to the market on a broad scale in the next 15 to 20 years. All national and international programs concentrate on cost reduction of both the fuel cell itself and the peripheral components.

The companies expect the residential market to accept specific unit costs of around 2,000 Euro/kW whereas the prices for the application in industry or utilities must be even lower, amounting to a maximum of 1,500 Euro/kW or less. The expectations of the expert Professor Garcke of the Centre for Solar Energy and Hydrogen Research (ZSW) Baden-Württemberg were source for the Figure 50, market accepted costs of fuel cell systems.

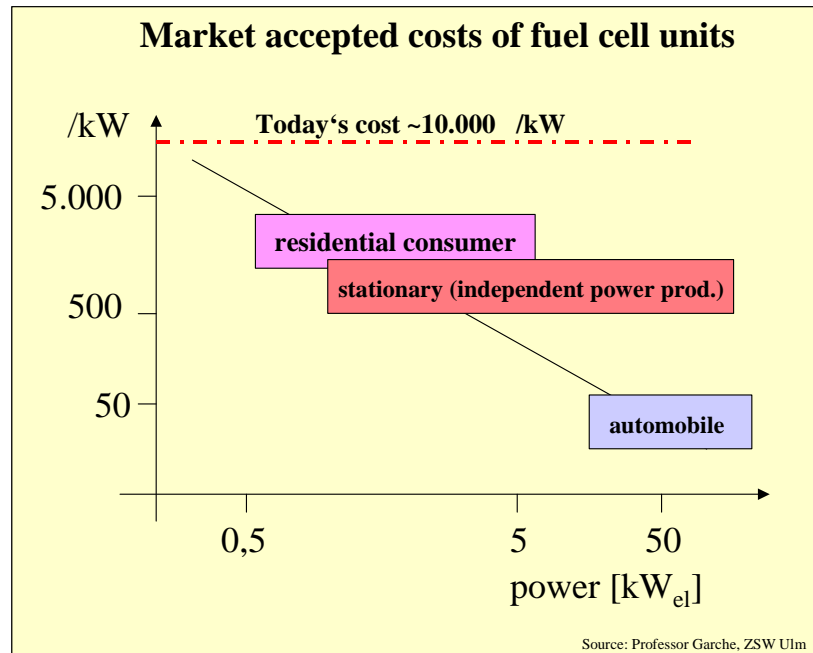


Figure 50: Acceptable costs for fuel cell systems

Another critical R&D issue is the improvement of the lifetime of the fuel cell system. At the moment there are single test or prototype systems which reach a lifetime of 10.000 hours. To become comparable to other systems or to become economically feasible, a lifetime of 40.000 hours for stationary applications is targeted. It is expected that several types of fuel cells can reach this goal within the next 10 or 15 years which should enter the market unless other barriers will occur.

Market entrance and timetable

As mentioned, most fuel cell types use hydrogen as fuel. If it is delivered in pure form it can be used directly. If, alternatively, gaseous/liquid hydrocarbons, biogas or alcohol are used, the fuel must be reformed, to generate hydrogen. Some fuel cell types have an internal reformer, others need an external one. In any case a fuel infrastructure like a pipeline grid and/or a truck transportation system must be available.

The fuel cell technology is not as simple as a boiler which is fired with coal, oil or gas, neither the system itself nor the fuel hydrogen or the fuel preparation and handling. A key barrier, from the today's point of view, are the overall costs of the system consisting of the core technology (fuel cell), fuel production (reformer) and fuel infrastructure. While the challenges are big, the advantage would be to realize a highly efficient energy generation technology leading to much lower greenhouse gas emissions which is a key driver for the current development. Because of the high requirements with regard to the technical know how as well as to the financial aspects, it is expected that fuel cells will start their career in the rich industrial countries where the people should have the needed know-how and the financial possibilities to enable the transition towards a changing energy economy.

Europe is a region where most of the suppositions are fulfilled for a successful development trajectory for fuel cells. A very preliminary skeleton proposal for the main elements and timelines of a European roadmap for the development of a hydrogen infrastructure and the implementation of fuel cell or hydrogen systems has been elaborated by the High Level Group and is presented in Figure 51 as a basis for wider consultation and discussion within the European community. Taking into account the current state-of-the-art of fuel cells the timetable of this vision corresponds quite well with the timeframe of VLEEM. Therefore, the assumptions made in the VLEEM calculations about the technical performance of fuel cell systems and the wide-scale introduction for mobile and stationary applications can be assumed to be realistic.

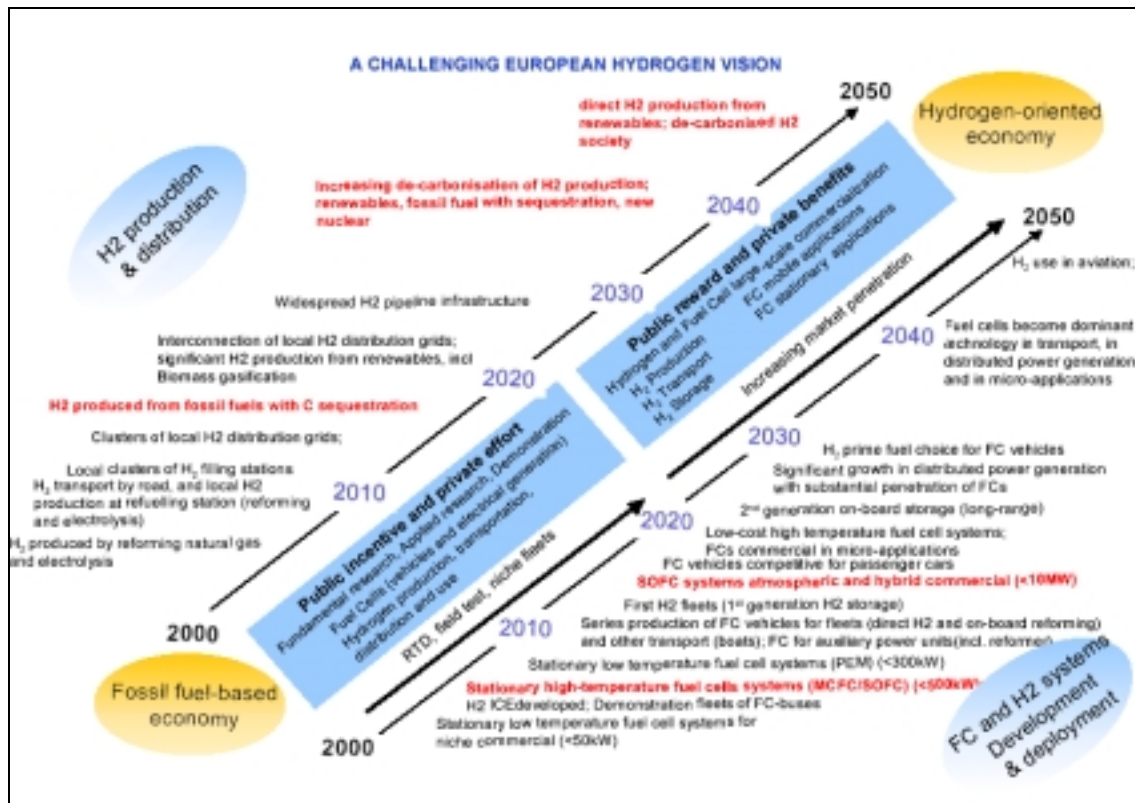


Figure 51: Skeleton proposal for European hydrogen and fuel cell roadmap
source: Vision Report of European High Level group, July 2003

3.2.3 Fuel choices in air transport

Next to internal combustion engines which nowadays account for the majority of energy use in the transportation sector (85% including ships) air transport is the most important consumer of energy in the transportation sector, with further substantial growth being expected (by nearly a factor 4 for Europe 33). As shown in Figure 3-6 substantial fuel efficiency gains are projected for air transport (close to 60%), which is a consequence of larger aircrafts, more efficient gas turbines and possibly higher occupancy rates.

In view of greenhouse gas emission reduction targets the possibilities of replacing kerosene in air transport have been discussed in quite some detail in the last few years (REF = IPCC) and are reported here: It is possible to design and operate aircraft gas turbines to operate on cryogenic fuels such as methane or hydrogen. However, this would require new aircraft fuel system designs and also new ground handling and storage systems. To reduce heat transfer, cryogenic fuels would have to be stored in the fuselage rather than the wings. These fuselages would have to be considerably larger than current designs because methane and hydrogen have only 65 and 25%, respectively, of the energy density of kerosene. Larger fuselages would increase drag and fuel consumption. In the case of long-range flights, this penalty would be compensated by a lower take-off weight because of the higher to somewhat higher specific energies of hydrogen and methane respectively. However, for medium- and short-range flights (5500 km and 3200 km) energy requirements increase by 10-40% (based on Momenty, 1996; quoted in REF=IPCC).

Hydrogen may be more attractive than methane from an emissions standpoint because CO₂ and SO_x emissions would be eliminated but, on the other hand, water vapor would increase significantly. The potential greenhouse effects of water crystals in the atmosphere would need to be taken into account when quantifying the overall effect for global warming (these effects of non-CO₂ emissions are not included in VLEEM-II).

3.3 Households

Household energy use depends on the number of households, the number of persons per household, wealth (size, number of equipment) and the consumption patterns, climatic conditions (determines the need for heating and cooling), current energy efficiency levels, which are partly determined by the technology level, partly by the fuel mix used and partly by other factors. Figure 52 shows the estimated composition of final energy use in households in selected world regions.

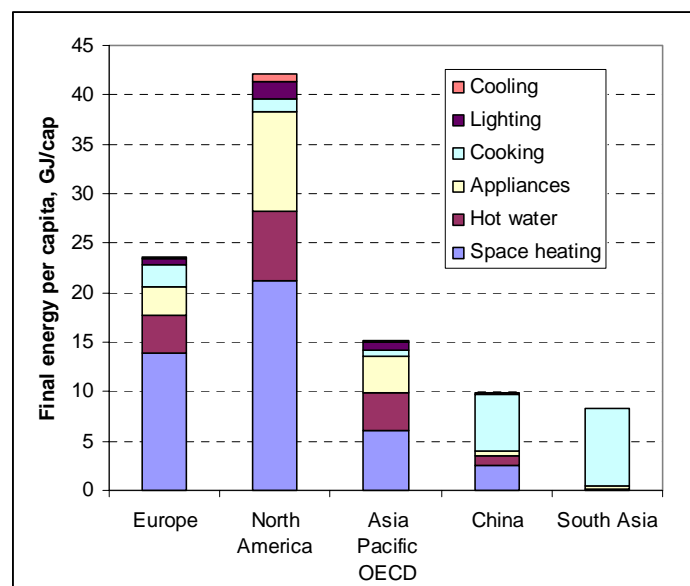


Figure 52: Estimated per capita final energy use for energy services in households in selected world regions, year 2000

3.3.1 Floor space and energy efficiency of space heating

Several energy services are related to floor space, in particular space heating, space cooling and lighting. The projected floor space requirements are shown in Table 3-3 for the reference case (MidPop). In Europe, space heating nowadays accounts by far for the largest amount of final energy used in households (Figure 53). On the other hand, it has been demonstrated that not only low energy houses but also passive houses and zero energy houses are technically feasible. Passive houses can be realized at acceptable cost and future R&D, in combination with adequate policy, is projected to allow to do so also for zero energy houses on a large scale (see specific energy data in Table 3-4). A simple vintage model was used to project the gradual replacement (incl. renovation) of the housing stock (see Figure 3-1 at the beginning of Chapter 3). This data was combined with information on the specific energy use of newly built houses (see shares in Table 3-4) in order to project total energy use of the building stock. It is projected that total final energy for space heating decreases in the reference case from 8,000 PJ in Europe in year 2000 to around 1,200 PJ in 2100, i.e. by 85%. Depending on the climatic conditions and the size and development of population, the savings projected for other world regions are in a similar order of magnitude (e.g. more than 5,000 PJ or 80-90% for North America and the Former USSR) or – in most cases – lower (e.g. Asia Pacific OECD). In some developing regions, more final energy might be required for space heating because higher comfort levels (more heated space, higher room temperatures) overcompensate the (very substantial) energy efficiency gains.

Regions	Floor space housing (m ² /cap)	
	2000	2100
Europe	33	52
N.America	61	76
Latin America	15	35
South Asia	9	25
China	10.5	27.5
Asia Pacific OECD	0	30
Other Asia Pacific	0	25
Former USSR	22.5	41
North Africa	0	25
SubSaharan Africa	0	22.5
World	16.1	24.2
World without EU	14.4	21.5

Table 3-3: Specific floor space for housing, in m²/capita

	Specific energy use MJ/m ² /a	Share of new buildings entering the	
		2000	2100
Zero energy house	0	2%	95%
Passive energy house, higher bound	54	5%	5%
Low energy house, lower bound	108	30%	0%
Low energy house, higher bound	252	63%	0%

Table 3-4: Specific energy use and share of new buildings entering the stock in Europe for the years 2000 and 2100

3.3.2 Energy efficiency of other energy services in households

Potential long-term energy savings differ substantially depending on the energy service in households. For **space cooling**, final energy savings of up to 40% have been assumed, with larger savings being achievable by means of adequate architectural measures. The major uncertainty with regard to cooling originates from the extent of space cooling demanded across the globe in this century. For **sanitary hot water**, the efficiency improvement potentials on the energy demand side are relatively limited for industrialized countries due to rather high conversion efficiencies nowadays and unavoidable losses due to distribution and storage. In developing countries, still major unexploited energy efficiency improvement potentials exist, in particular when coal and biomass are used as fuels for hot water preparation. In industrialized countries, primary energy savings related to hot water can be achieved, in particular, by use of renewable energy such as solarthermal panels, geothermal energy and seasonal heat storage in combination with heat pumps (the analysis of these saving potentials including measures on the energy supply side is covered in Chapter 4). Similar to sanitary hot water, the potentials to improve specific energy consumption of **cooking** is rather limited in industrialized countries, with major inefficiencies being observed in particular in developing countries. Apart from technically defined efficiency, cultural differences in preparation across countries and world regions and the increasing consumption of convenience food (especially in combination with microwave preparation) explains widely differing values for specific energy use nowadays which may persist to some extent in the longer term. For **electric appliances**, two groups can be distinguished. The first group is composed of appliances which are well established on the market and for which not only current specific energy use is well known but also future energy use can be projected rather well. For example, for **lighting** a relationship can be established with floor space and there are limited and rather clear technological options (compact fluorescent bulbs and LED bulbs with specific energy savings compared to incandescent bulbs of 70% and 90% respectively). Similarly, the situation is rather clear for food conservation (refrigerators and freezers), for dish washers and for washing machines. For all other appliances, such as entertainment and other household appliances (including also saturation degrees of more than 1 per household and, in particular, new products) the situation is more diverse, hence rendering this energy demand category a major source of uncertainty for overall household electricity use.

3.3.3 Summary of final energy use in households

Combining the assumptions outlined above leads to projections for final energy use for all VLEEM regions. As shown in Figure 53 there is a very large potential to reduce final energy use for space heating both in Europe and in the rest of the world. The latter is remarkable in view of the anticipated development of low-income regions of the world, some of which will also require heating. World-wide, hot water will contribute by far most to the increased final energy requirements of households, thus reflecting the limited possibilities to improve energy efficiency for this demand category and the need to account for this by suitable strategies on the energy supply side. As a further macro-trend, the total power requirements for space cooling and electric appliances are anticipated to increase substantially from 2000 to 2100 (doubling for Europe and more than 10-fold increase for the rest of the world). For Europe (EUR 33), energy use for space cooling might increase from practically negligible amounts nowadays to around 15% of final energy use in 2100. Final energy use for the total of all

electric appliances is projected to increase in Europe because energy efficiency gains are overcompensated by new energy services.

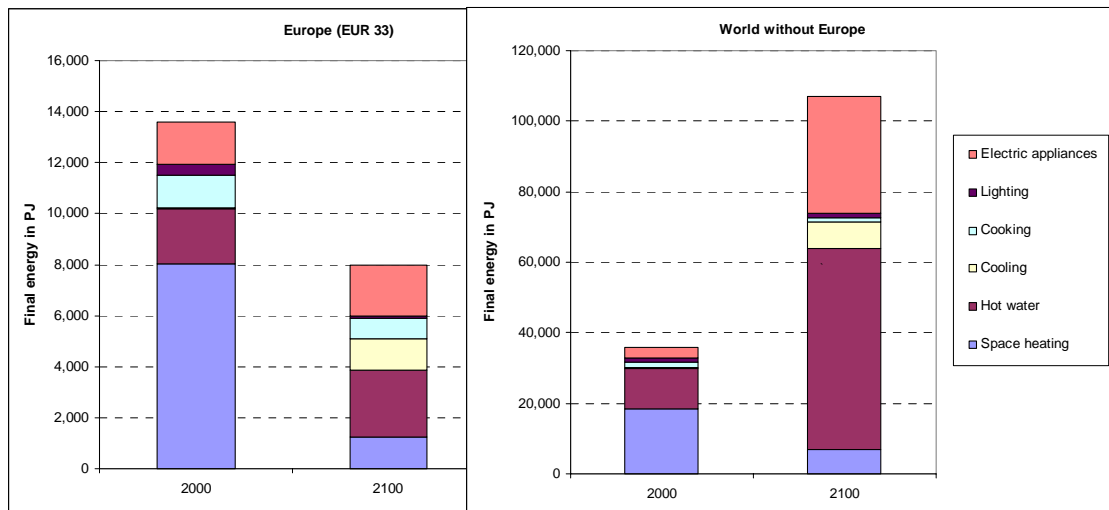


Figure 53: Final energy use for households in Europe (left) and in the world without Europe (right), year 2000 and 2100

3.4 Tertiary and remaining manufacturing sector

In VLEEM, the tertiary and remaining manufacturing sector includes firstly all large-scale industrial activities except for the manufacture of the nine bulk materials covered in Section 3.1 and secondly all services and small consumers such as craftsmen and small-scale manufacturing, restaurants and hotels, sport facilities, retail, banks and insurances, media, all governmental institutions (e.g. schools, hospitals and tax offices) and all activities operated by municipalities (e.g. administration).

Important energy demand services in the tertiary and remaining manufacturing sector are space heat, space cooling, mechanical energy, process heat, refrigeration (process cooling), lighting and information and communication technologies. Several of these energy services have been discussed above, including the attendant assumptions for energy efficiency improvement and will therefore not be discussed in this section. Given the large heterogeneity of the tertiary and remaining manufacturing sector, many of the other energy demand services are highly case-specific (e.g. savings of process heat in the bakery sector) and are therefore not covered in detail in the VLEEM model. Simplified assumptions are being made in these cases, leading to overall relationships which are made use of in the integrated energy demand and energy supply analysis in Chapter 4.

3.5 Summary on energy efficiency

Figure 54 shows energy efficiency indicators for all sectors distinguished in the VLEEM model, i.e. for industry (bulk materials), passenger transport, freight, households and the tertiary & remaining manufacturing sector.

As shown in the graphs the specific energy use for the production of the total of all **bulk materials** is somewhat larger in Europe than in the rest of the world. This has mainly to do with the shares of the various bulk materials (production structure): especially polymers, which are energy-intensive products, play an important role in European industry, in particular when compared to developing countries. Hence, while the specific energy use for the individual bulk materials in Europe is on the lower side in Europe compared to other countries (not visible from Figure 54), this advantage is overcompensated by the production structure, leading to the overall values shown in the graph. In both industrialized and developing countries the overall (physical) specific energy use is projected to decrease by around 1/3 (Figure 54).

As for bulk materials, the overall specific energy use for **passenger transport**, expressed on MJ per person-kilometer, is also larger in Europe than in the rest of the world (Figure 3-11). The main reasons are that the share of public transport (which is generally much more energy efficient than individual transport, see Figure 3-6) and the occupancy rates are higher in developing countries than in industrialized countries. While differences also exist between industrialized countries, they are not the reason for the difference displayed for passenger transport in Europe and the rest of the world.

For **freight**, identical data for vehicle efficiency data were used for the various world regions because more accurate information was not available. Since, moreover, the modal split does not differ drastically in the various regions, the overall results for the years 2000 and 2100 are very similar for Europe and the rest of the world (Figure 54).

Energy efficiency in **households** is expressed in Figure 54 as primary energy equivalents per population and is substantially higher in Europe compared to the rest of the world, especially in the year 2000. This is mainly the consequence of the low energy use in households in developing countries for climatic reasons and due to lower income levels. For 2100, the difference between Europe and the rest of the world is projected to be relatively small because industrialized countries are expected to have reduced drastically their energy use for space heating while power consumption for appliances more and more converges in the various world regions.

The specific energy use of the **tertiary & remaining manufacturing sector** increases considerably both in Europe and in the rest of the world (Figure 54). This has mainly to do with the growth of this sector which outweighs the progress made in energy efficiency.

As discussed in Section 3.1 to 3.4, the energy efficiency improvements projected for the year 2100 are very substantial for all sectors even though this is not always obvious from Figure 54. The realization of the efficiency gains displayed here will hence entail major efforts in research, development and large-scale implementation of low-energy technology across the globe.

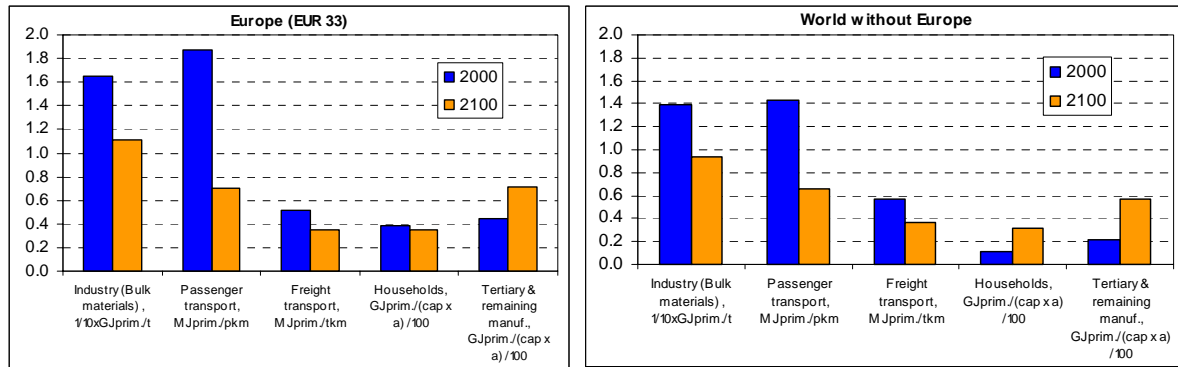


Figure 54: Summary of energy efficiency (in primary energy terms) in Europe (left) and in the world without Europe (right), year 2000 and 2100

3.6 References

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4. Chapter 4: 3 cases for energy systems in 2100

The following description should certainly not be misunderstood as final analysis, which presents results, which could already be feed into a political decision process, the following result is more an illustration of the methodology. While most of the current energy models, like Message, Markal or TIMES try to simulate a market economy, this is not even tried here. The analysis is much more qualitative, and is focussed on Europe.

4.1 First Case: Fossil fuels

4.1.1 The challenges

Fossil fuels supply more than 80 % of the primary energy demand in 2000 (IEA, 2004). The total energy demand is expected to increase in the next decades. The share of fossil fuels is even expected to increase in the short term (IEA, 2004). Fossil fuel demand is therefore rapidly increasing. Recent increases in the oil, but especially coal price reflect this issue. Two major challenges are expected for the future. 1.) Resources of fossil fuels which are not available today or only at unacceptable high costs, need to be made available at competitive prices. This requires massive investments in exploration and mining infrastructure. 2.) The unavoidable stream of CO₂ emissions need to be captured and stored safely for centuries. Only if both challenges can be solved without major cost penalties, fossil fuels will remain the main energy sources, even in a future, in which sustainability criteria are applied.

The availability of fossil fuels is reported at various sources. Numbers of reserves are mainly stable over time and sources, while numbers of resources differ considerable. In the following investigation the values published by BGR (BGR, 2002) will be used as reference. The results for the major fossil energy carriers are quoted in table 1.

	Reserves	Ressources	Fraction of Ressources	Total Recoverabl e World	Fraction of use in Europe	Total Recoverabl e Europe
	[EJ]	[EJ]	[%]	[EJ]		[EJ]
Conventional oil	6360	3515	0.7	8820.50	0.07	617.435
Unconventional oil	2761	10460	0.5	7991.00	0.07	559.37
					0.07	
Conventional gas	5109	6886	0.7	9929.20	0.07	695.044
Unconventional gas	63	48633	0.5	24379.50	0.07	1706.565
					0.07	
Coal	17668	103898	0.5	69617.00	0.07	4873.19
Lignite	1963	12218	0.7	10515.60	0.07	736.092
					0.07	
Uran	644	2139	0.7	2141.30	0.40	856.52
Thorium	908	964	0.7	1582.80	0.07	110.796
Sum	35476	188713		134976.90		10155.012

Table I: Table of energy reserves and resources. Source: BGR

The most important fossil fuel for the future is coal. Coal makes up for more than fifty percent of the combined reserves and resources. The rather high values for unconventional gas resources, which were discussed in the last ten years, were questioned recently. The values quotes here are certainly more in a conservative range.

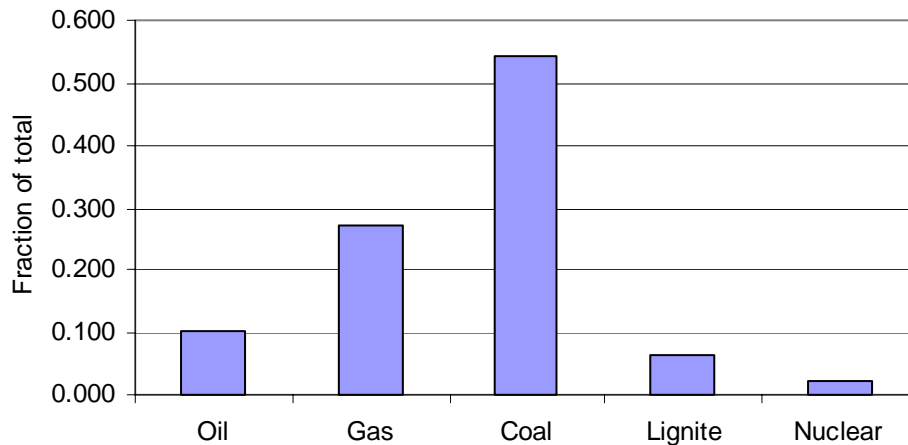


Figure 55: The picture gives the fraction of the combined reserves and resources for the various energy sources from the total amount of reserves and resources.

Two major assumptions need to be made. First it needs to be decided, which fraction of the fossil fuel resources will become reserves over time. Second question is, which fraction of the reserves and resources will be available to Europe. The first number will strongly depend on the technological progress in mining and exploration technologies and of course on the nature of the resources itself. Recent debates about the size and availability of gas hydrates highlight the later issue. The fractions used here are only vague estimates. A detailed analysis of exploration and mining technologies was not performed within VLEEM. The second question is resolved within the VLEEM methodology, the amount of resources is equivalent to the needs within in Europe. For Europe this would require 7 % of the global resources. Any kind of distribution is open to questions and reflections of the underlying justice.

The second major challenge concerns the GHG emissions. As a sustainability criteria it was assumed that every decade the amount of emissions is reduced by 10 %. Till 2100 Europe would have to reduce its GHG emissions to 35 % of the current level. This requirement is modest compared to some political requests to reduce GHG emissions in OECD countries by 80 % till 2050. But even the reduction by 35 % till 2100 poses a severe challenge.

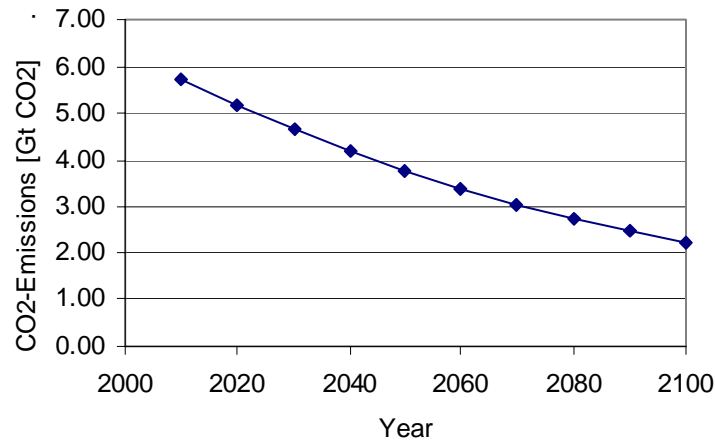


Figure 56: Europe is expected to reduce the GHG emissions by 10 % every decade.

The emission path assumed for Europe is shown in figure 56. Concerning this path Europe would have to reduce emissions by roughly a factor of three until 2100. CO₂ emissions related to energy occur in all final energy sectors. A rough distribution of energy related CO₂ emissions of the EU is given in figure 57. From the picture it becomes obvious that priorities in CO₂-emissions reduction concern first two sectors, electricity and transport, then buildings and last, industry.

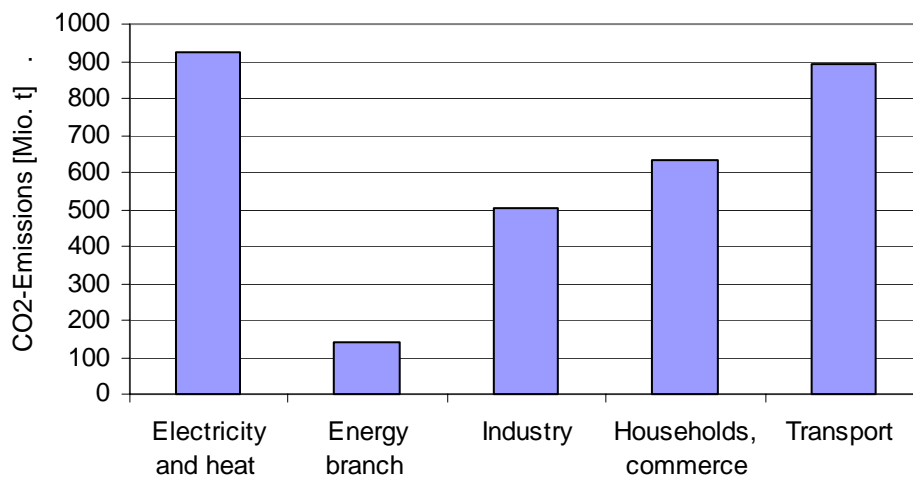


Figure 57: The absolute CO₂ emissions of EU in the various sectors in 2003

The reasoning behind the selection of the sectors in which most reductions are expected involve again political, economic, environmental and acceptance reasons. The recently introduced emission trading scheme within the EU demonstrates that an equal treatment of all sectors can not be expected from political measures. In the EU emission trading scheme only point sources having more than 20 MW thermal power are regulated.

4.1.2 Fossil fuels as final energy carriers

Fossil fuels do still reach the consumer as final energy carriers, mainly natural gas, various oil products, including gasoline, and coal for industry mainly. Even in a high fossil fuel case this is expected to change for the simple reason, that the CO₂-emissions of final energy carriers can only be captured and stored economically in large central installations. The question is, in which sector should fossil fuels still be used and which sectors should be switched to hydrogen and electricity.

We assume that Europe will not be allowed to emit more than roughly 2 Gt. CO₂ equivalent in the year 2100. This corresponds to 37 EJ of natural gas, 25 EJ of oil and a little less than 22 EJ of coal, which could still be combusted without capture and storage of CO₂-emission. A key question in this respect is, will hydrogen make a major contribution at that time in the final energy sector, or will energy savings and electricity together with the above mentioned rest be sufficient to supply all energy services. Taking also into account that roughly 27 EJ/a of natural gas would be available for Europe per year, it makes sense to utilise this source for uncaptured combustion first.

Transport sector

Major car suppliers announced the introduction of fuel cells as early as the first decade of the 21st century. This was often seen as the first step to a hydrogen economy. Fuel cells do not only promise to be very efficient, but if they are fuelled by hydrogen they do not produce any kind of toxic local emissions. The later argument makes them especially suited for areas with high population density. The announcements of the car industry became more modest recently and the introduction of a hybrid car, a car with ICE and electric motor, opens another possibility to increase the efficiency of the car. Most of the early announcements were revised and the fuel cell became again a technology for the long term.

As a starting point for the set-up of the case a couple of transport options should be investigated and compared. First of all the transport sector could shift most of its problems to the electricity sector, if a major shift in transport modes could be initiated. Certainly major trends do not hint in this direction, although especially the introduction of high-speed trains offers attractive alternatives for inter-city transport.

Different fuel and traction concepts for road vehicles are compared. For the first investigation no sequestration of CO₂ is assumed. The comparison is not made for cars producing hydrogen on board from ordinary fuels of fuel cells which can directly utilise hydrocarbons. The result of the comparison is shown in figure 4. Certainly it is striking that hybrid cars running on natural gas perform quite well compared to hydrogen driven fuel cell cars. The latter option certainly offers the possibility to sequester the CO₂ during hydrogen production. Options like the enhanced use of bio-mass will be discussed later.

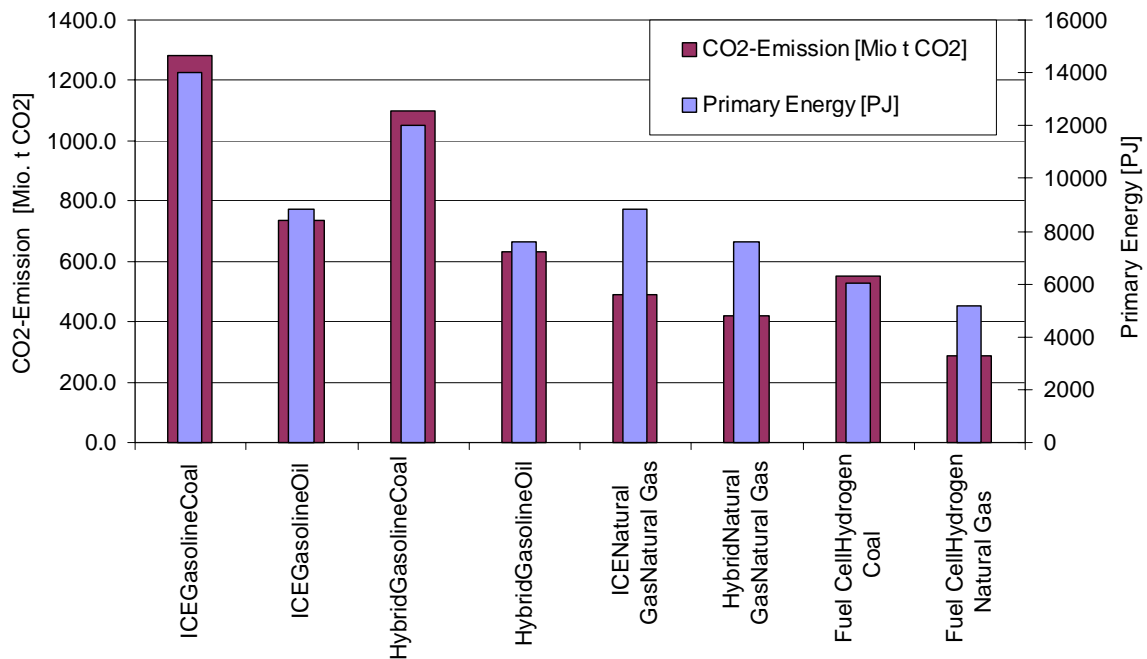


Figure 58: The primary energy demand for different fuel and traction systems.

Recent studies have questioned the rationale to introduce hydrogen in the transport sector by questioning the overall efficiency of the supply chain (Bossel, 2003). The arguments are related to the comparable high losses in the transport and storage sector necessary for a hydrogen infrastructure. In the comparison a transport and storage efficiency of 80 % was assumed. The fuel cell option remains still the most efficient one. The next possible criticism is related to the high efficiency assumed for the fuel cell. The numbers do not reflect results of recent developments, they do more reflect principle limits posed by the underlying physics. The development of conventional power plants is certainly a good example to show that physics limits, given here by the Carnot cycle, are step by step approached within a hundred years development.

The assumption is that the transport sector in 2100 is dominated by natural gas as fuel. The CO₂ emissions of the transport sector would stay even under 1 GtCO₂/a (roughly 400 Mio. t of CO₂ for the private cars as dominating factor). Conventional cars would be replaced by hybrid cars. Planes would still fly on kerosene. This can certainly be considered as very conservative assumption, no acceptance problems in the public, no major technologies need to be developed, only the existing infrastructure of gasoline stations has to be replaced by natural gas filling stations, which do exist already today, even at a very high density in some countries (Netherlands, Italy).

The housing and service sector

The development in the housing sector can be characterised by two trends, increase in electricity demand for various electrical appliances and strong reduction of heat demand especially for new houses. It is assumed that all houses build after 2010 follow rather strict heat standards ($< 25 \text{ kWh/m}^2$) for space heat demand. (The question is, can this be reached by wall insulation and improved windows or would we need even recovery of air circulation, which is sometimes strongly undermined by user behaviour). Assuming that the new building

standards are also capable of avoiding major demands for cooling in summer, no major cooling demand is assumed. At the end of the century it is assumed that the central final energy carrier reaching households is electricity. It needs to be stated that this assumption requires quite early actions by the national and European administration to assure that the new housing standards, which are certainly technical achievable at acceptable costs, will be applied everywhere in Europe.

A couple of end-use technologies utilising various fuels can be applied to deliver the heat. New gas and oil condensation boilers, electric resistance heating, heat pumps driven by gas or electricity, small combined heat and power plants (CHP), based on various technologies like micro-turbines, Stirling motors and in the future fuel cells, district heating and geothermal heat.

It is assumed that for the existing housing stock a variety of heating technologies is applied. The new houses are only supplied by electricity, if possible using heat pumps.

Industry sector

Industry still uses the whole variety of fossil fuels: coal, natural gas and all kind of oil products. Industry does also consume electricity and even hydrogen. The choice of the appropriate final energy carrier depends on availability, costs and environmental issues. Industry could be the first sector using large amounts of hydrogen, it seems also feasible that in major industries CO₂ emissions are captured and sequestered.

The fossil fuel case assumes that not much new technologies enter the scene. Since CO₂ capture will be necessary in any case in the electricity sector, it is assumed, that this technology is also supplied in the industry sector. The CO₂ transport infrastructure transporting CO₂ from the power plants to the stores will also be used by industry, but at a much later stage.

4.1.3 Technologies

Fossil fuels dominate the energy system. Most energy technologies, power plants, boilers, traction system, need fossil energy carriers as fuels. Some of the technologies like the internal combustion engine (ICE) look back to a more than hundred year history. Their development status is very advanced. But still a continuous improvement can still be observed. The development the efficiency of power plants should serve as a reference. Steam turbines were developed at the end of the 19th century, gas turbines as plane engines during the Second World War. The increase in plant efficiency is documented in figure 5. Most of the technologies for a high fossil case are developed.

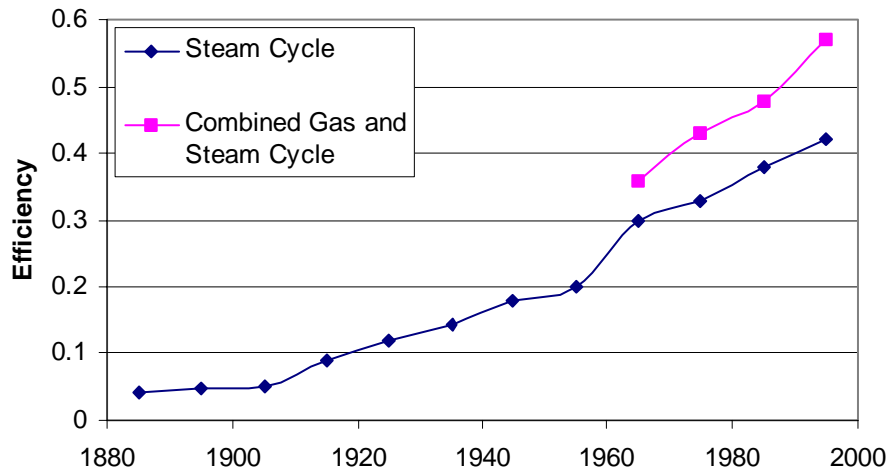


Figure 59: Development of the efficiency of the steam cycle.

The central new issue for the fossil technologies is the separation of the CO₂. Only if this can be achieved the sustainability criteria can be fulfilled. CO₂ separation is a proven process technology. CO₂ is used in many industrial processes. A prominent application is the use of CO₂ for enhanced oil recovery. The question is therefore not if CO₂ can be separated, but how the additional process steps will influence the technical and especially economic performance of the various energy conversion technologies.

A whole family of concept studies is underway to include CO₂ separation into power plants, either coal or gas fuelled. In the following we will focus on coal power plants only. Three major technology lines are discussed: Internal Gasification Combined Cycle coal power plants with CO₂ separation in the gasification step. In this line the carbon is separated from the fuel before the combustion process. The remaining fuel is the hydrogen. The second option is to keep the combustion under an oxygen atmosphere, the flue gas stream is then already highly enriched CO₂. The third and last option is to separate the CO₂ from the flue gas, various adsorption and adsorption methods, cold traps or membranes can be used.

The remaining major issue is the identification and qualification of suitable CO₂ stores. The stores need to be capable of storing 4 Gt of CO₂ every year at the turn of the century, and to keep the CO₂ for many future centuries. Accidents with a sudden release of major amounts of CO₂ need to be excluded. Again a family of options is discussed. For a detailed discussion see (Turkenburg, 1997). Most of the discussions focus on geological storage formations or on the ocean. It should still be mentioned that it is possible to convert the CO₂ exogenously to carbonates or other solids. Without any doubt such an additional process step would again challenge the technological and economical performance of the technology, but it would certainly be the safest option and would relax all limits of the storage size.

In the discussed case hydrogen enters only as energy carrier and chemical agent in process steps in the power plants or large industrial installations. A high fossil case in which hydrogen would become a major final energy carrier, for transport, industry and households could also be imagined. Still compared to the discussed case a complete new infrastructure would be necessary. Therefore this option was excluded, since the philosophy was to minimize the necessary changes.

4.1.4 Balance case Europe

A high fossil case means in the end a high coal case. Coal is by far the most important primary energy carrier in this case in the year 2100. This result is certainly consistent with the resource expectations. Only in a few niche markets oil is still used. Certainly most of the coal would not be produced in Europe. Efficient and cheap coal transport is only possible on sea and major rivers or canals. The necessity to store CO₂ makes the sitting issue even more complex. In the beginning of industrialisation industry moved or was new created at the coal fields. Now industry, especially the power plants, will move to the places, mainly at the sea side, which offers cheap and easy access to the world coal market and of course where CO₂ stores are available.

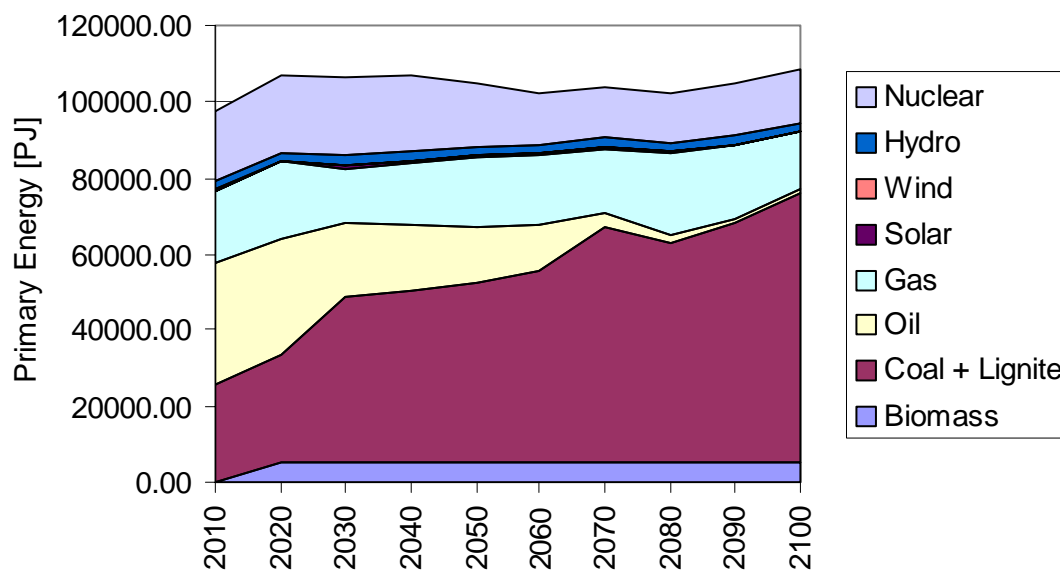


Figure 60: Development of the primary energy supply in the high fossil case. Coal and gas would be the main energy sources at the end of the century.

The sheer amount of carbon that needs to be stored is enormous. Handling the CO₂ “waste” becomes a sector of the economy which is not negligible. Regulations, safety and environmental standards of CO₂ stores will be under continuous scrutiny. Possible CO₂ accidents might challenge the public acceptance. On the other hand will the whole economy very much dependent on the coal price, much more than today on the oil price, especially the electricity price will be directly coupled to it.

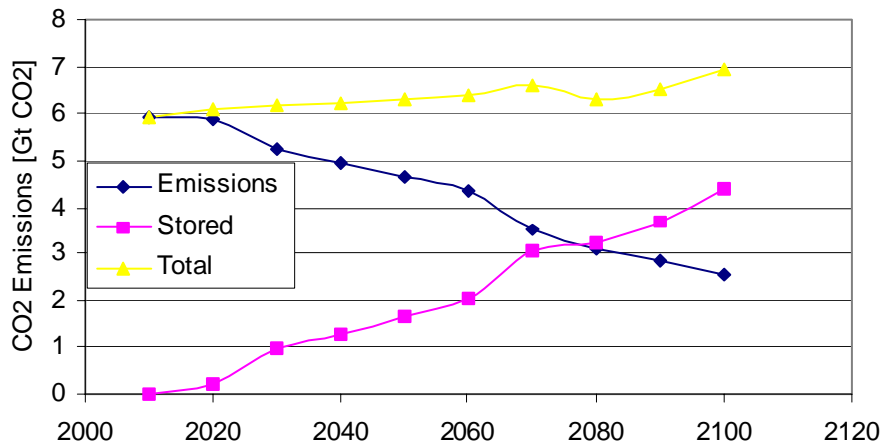


Figure 61: The figure describes the development of the CO₂-emissions and the fractions which are released to atmosphere or stored. In 2100 more than 4 Gt CO₂ need to be stored each year.

The **transport sector** undergoes shifts, first a reduction of the demand due to the introduction of new efficient hybrid road vehicles, then a fuel shift from oil to natural gas.

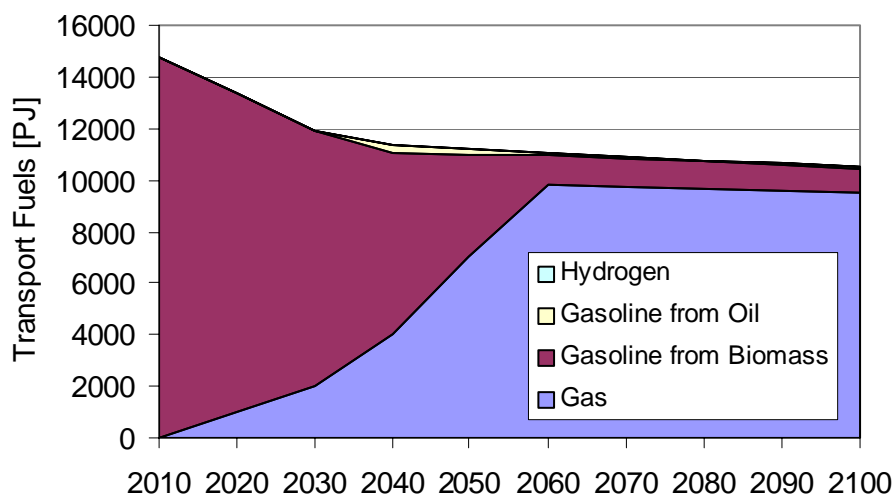


Figure 62: Development of the end-energy demand in the transport sector.

The overall final energy demand of the **residential sector** will peak at roughly 19 EJ between 2020 and 2030, the commercial space heat demand accounting for 13 EJ in the total. It will then decline steadily afterwards, due to the sharp decrease in the commercial space-heat demand, down to 11 EJ in 2050 (14 EJ in 2003), among which roughly 5 EJ for space-heating.

The space heat demand of newly build houses will be rather low. The heat demand of the now already existing houses will dominate the heat demand until the eighties of the 21st century. Electricity is expected to account for 90% of the total final demand of the residential sector at the end of the 21th century.

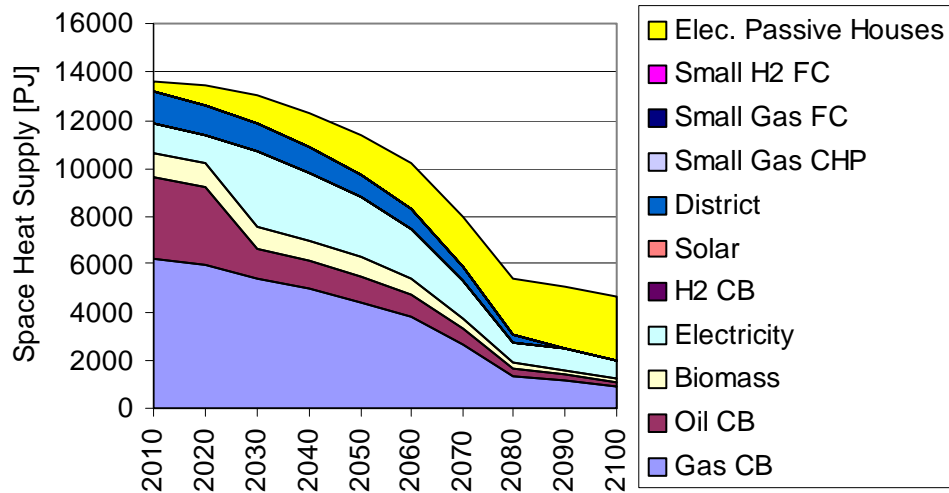


Figure 63: The development of the space heating systems. In the year 2100 most houses have reached passive house standard and are supplied by electricity.

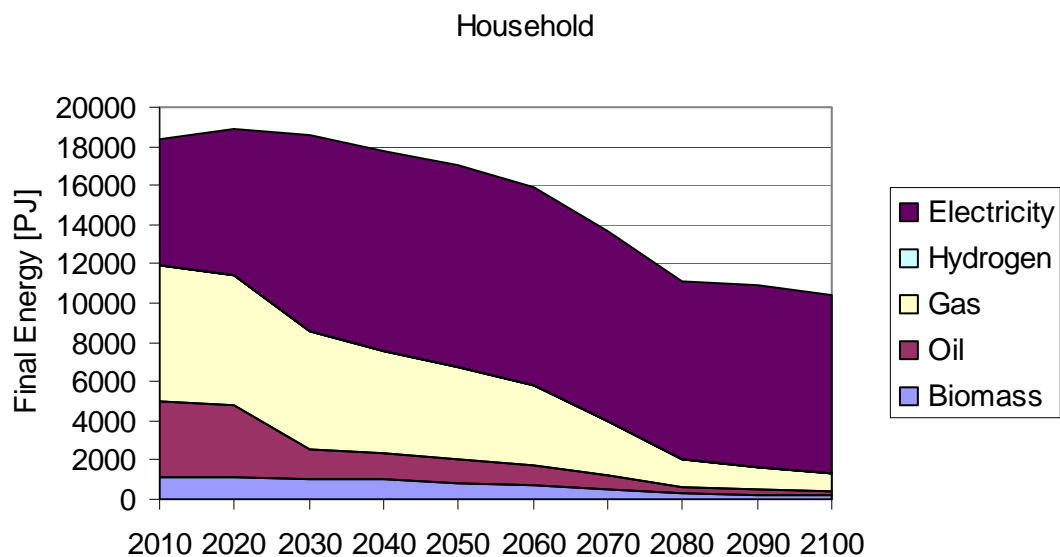


Figure 64: Development of the end-energy demand in the residential sector.

The final energy demand of the **production sector**, industry, construction and services, will continue to grow slowly and regularly over the whole century, from 28 EJ in 2003 up to 44 EJ in 2050.

Coal is expected to play a significant role in bulk industries (thanks to abundant reserves worldwide and carbon sequestration), and oil will be used almost exclusively as feedstock. Natural gas, which is expected to play a minor role after 2030 will be partly replaced by hydrogen after 2050. The share of electricity in the total demand will remain roughly stable.

Industry

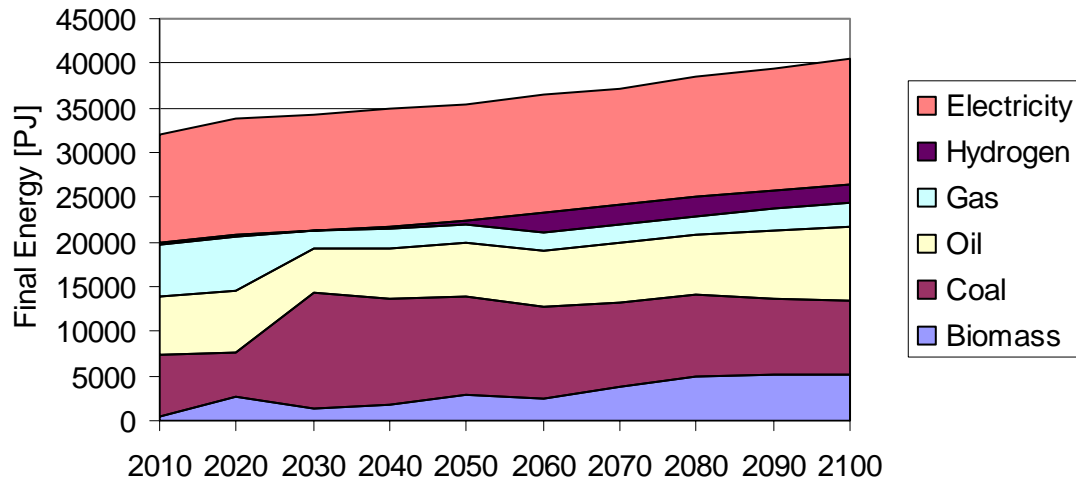


Figure 65: Development of the end-energy demand in the production sector.

4.1.5 Major milestones

The major milestones and developments of the case are described in figure 10. The most important milestones are the feasibility test for zero emission coal power plants and the EU regulation for the housing sector. The zero emission coal power plants are certainly not competitive without special regulations. Since all cases assume that the CO₂ emissions in Europe have to decrease by roughly 10 % every decade, it is likely that the emission trading scheme would be continued over the complete century. CO₂ prices of 40 EURO/t CO₂ could make zero emission coal power plants competitive to conventional coal power plants. In the following the major milestones should be explained a little more in detail.



Figure 66: Major milestones for the high fossil case.

Zero Emission coal power plants

In the outline of the case coal power plants with sequestration play a major role. They deliver roughly 70 % of the electricity demand in 2100. In various national and international research projects coal power plants are under design. Major projects in the US are the FutureGen and ZECA project and in Europe for example COORTEC. As already mentioned a multitude of technologies is in principle possible, a good review can be found in (Hendriks, 1994). One key element might be the further development of Internal Gasification Combined Cycle power plants. Several IGCC demonstration plants are under operation, but without CO₂ separation.

Identification of storage options

The identification and qualification of storage options and the control of existing stores would be a permanent issue, if CO₂ sequestration becomes a widespread applied technology. The humanly produced CO₂ stores would compete in size with natural CO₂ stores like the atmosphere. Therefore very special attention has to be put to this issue. Certainly in a sustainable energy future it would be desirable to identify options, which could be sustained without human surveillance. The most attractive option in this respect is the solidification of the CO₂, especially as carbonates. Ideas in this direction do exist, further R&D in this directions seems desirable, if CO₂ sequestration becomes a major option.

Build of CO₂ collection and transport infrastructure

The case would initiate the construction of a major new infrastructure, namely a pipeline system to collect CO₂ emissions and to transport the CO₂ to suitable storage places. Power plants will move to coal harbours and major CO₂ pipelines.

Reduction of space heat demand

The housing sector is by far the sector with the biggest inertia. Houses build today might still be in use in hundred years from now. The housing sector deserves therefore a very special attention and needs very early actions. The most recent EU housing directives do aim in this direction. Still these directives are not strict enough to realise the strong reductions assumed in the case.

Shift from oil to gas in the transport sector

The transport sector is today completely dominated by oil. But the resource base of oil is too small to make a sustained supply of oil likely for the complete 21st century. One alternative is natural gas, which has to advantages, 1. the resource base is larger, especially if unconventional resources are considered and 2. natural gas has a specifically lower CO₂ emissions. Today natural gas is mainly used for heating and in the power sector. Since the design of the case is such, that neither in the power sector, nor in the heating sector natural gas is used, it can be used in the transport sector.

4.1.6 High fossil case with Fusion

One of the major R&D items of the EU and some of the EU member states is the development of nuclear fusion. A very important question is which role nuclear fusion could play in the cases presented here. Nuclear fusion will not be commercially available before 2050. In principle all three cases leave space for new technologies, if they are cost competitive and fit to the rest of the system. This is certainly the case in the high fossil case. It was assumed that step by step coal power plants with sequestration gain 70 % of the electricity market. Certainly, the system development would be simpler, if fusion power plants are built instead. Here it is assumed that in 2100 20 % of the electricity market will be covered by fusion. A couple of reasons exist, which would favour the additional installation of fusion. First, the plants would be preferably be sited at cost lines or at least rivers, a considerable CO₂ sink has to be close and enough high voltage lines need to be installed to transport the electricity to the demand centres. The constraints for possible sites of the fusion plants are much more relaxed. This would certainly simplify the network structure and other issues.

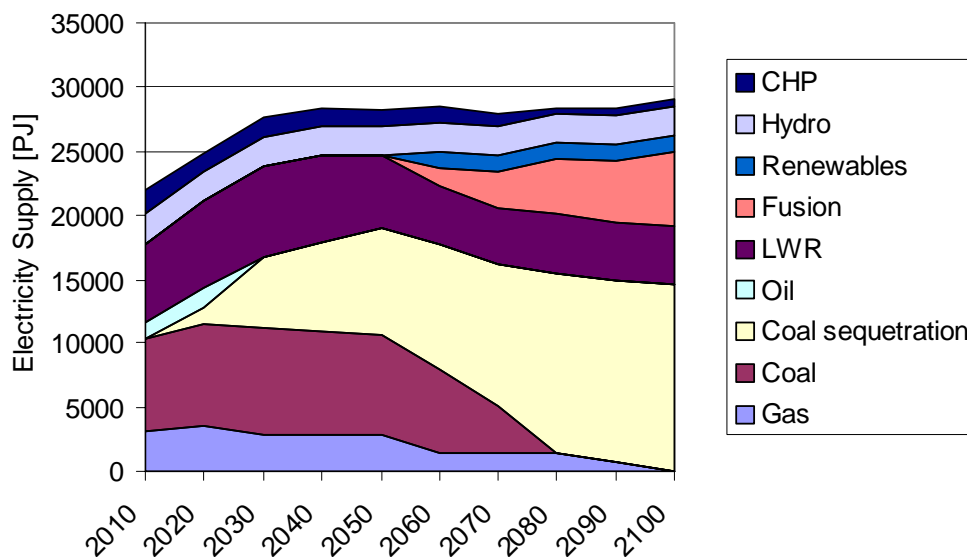


Figure 67: Electricity supply in the high fossil case with fusion. Beginning 2050 fusion starts slowly to gain market shares in the electricity system.

Another reason is that the dependence of the energy economy from coal prices would become paramount in the high fossil case, installation of fusion plants would also reduce this dependence.

Major Milestones:

The major milestones necessary to develop nuclear fusion are shown in figure 12. The milestones can be grouped in the three categories: construction and operation of ITER, development of materials and construction and operation of DEMO.

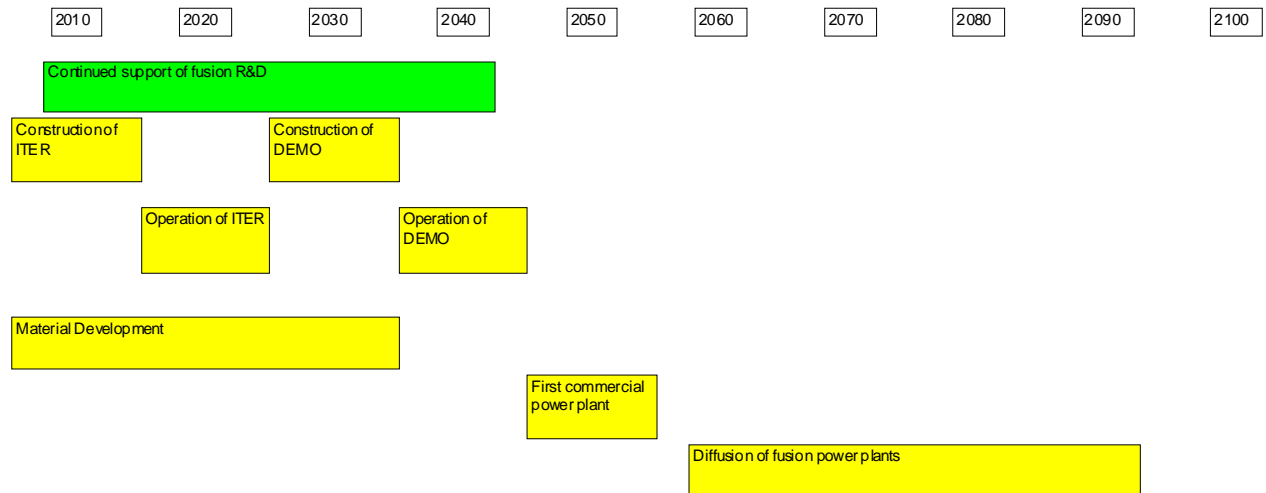


Figure 68: Major milestones for a high fossil case with additional fusion power.

Then of course fusion needs to be able to capture a certain market share. This will of course strongly depend on the cost of fusion plants. First estimates of these cost, which can of course only be made with a strong uncertainty, indicate that the cost of fusion power plants would not be prohibitively high and that it is likely that fusion enters the market if sustainability criteria are postulated.

4.2 Second Case: Nuclear

4.2.1 The challenges

Nuclear is currently supplying 30 % of the European electricity demand and in individual member states up to 80 %. The challenges of nuclear power for a sustainable energy future are as follows: will the resource basis be able to supply the demand or will breeder technologies become necessary, can an operation free of catastrophes be guaranteed, will it be possible to reduce the long lived waste to small, acceptable amounts.

In the past, several strategies were developed which would in principle be able to supply electricity from nuclear for many centuries to come. These strategies involved a mix of breeder, high temperature and converter reactors. The goal of these strategies was to develop a kind of closed nuclear cycle which would supply electricity of the order of $(10^8 \cdot 8760)$ TWh with low fuel input (of the order of a few thousand tons of uranium and plutonium) and fuel output which is less than a few thousand tons of fission products. The development of breeder reactors and reprocessing plants dominated energy research in the seventies. Major projects

were planned, constructed and some of them came even to operation. The success of most of the projects, like Super Phenix and Monju, are questionable. The success was not challenged by principle problems, actually was the first nuclear reactor constructed by Fermi already a breeder reactor, it was challenged by technical problems mainly caused by the cooling medium sodium. Concepts utilizing other cooling media are in principle possible.

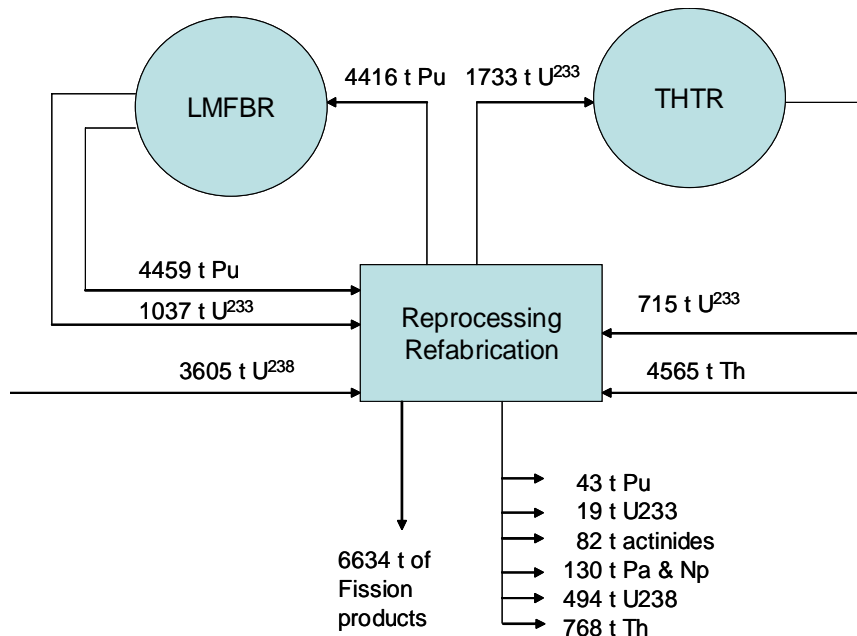


Figure 69: Energy studies in the late seventies and early eighties investigated already the possibilities and implications of a high nuclear case. The use of Liquid Metal Fast Breeder Reactors (LMFBR) in combination with Thorium High Temperature Reactors (THTR) seemed to be one option to reach a nearly closed loop in nuclear technology (picture: Häfele).

There is no unique strategy in the fission community to develop again an integrated fission system, which could supply electricity for many centuries to come with very low fuel demand and very low waste production. The most prominent research initiative is the Generation IV initiative. Some of the reactor types, which are designed within this initiative, are breeder reactors. The resource restriction is strongly relaxed in the following case. Otherwise a high fission case could not be designed. This means that parallel to conventional converter reactors new reactor types need to be developed, which have a much better fuel utilisation. An alternative could be that much more uranium is available at higher prices. Uranium cost account today for (0.1-0.2) EuroCent/kWh. Even if the price would be tenfold, the price of electricity would stay competitive. Another consideration seems to be necessary here. Since fission is only considered to be competitive if the long lasting waste can be efficiently destroyed, fast reactors and reprocessing plants need to be developed. These technologies can then also be used to breed new fissile fuel.

4.2.2 Final energies for the nuclear sector

Nuclear power plants can produce heat, which can be transformed to electricity and in future also into hydrogen. Electricity and hydrogen will therefore play a major role as final energy carriers. In the history of fission, it was expected that fission would also be used as heat

source for district heating systems and as traction system at least in ships. Nuclear power is still used in submarines.

Transport sector:

The high nuclear case offers the opportunity to supply hydrogen produced in high temperature reactors. Thermo-chemical water splitting is in principle possible. The efficiency would be roughly 50 % and is slightly higher than the production of electricity first, which is then transformed via electrolysis to hydrogen. None of the two technologies is available yet. Therefore it is assumed that this option is only available at the second half of the century.

Housing:

The housing sector is expected to be the same as in the high fossil case. The sector is characterised by strong reductions of the space heat demand and the introduction of electricity as final energy carrier for new houses. In the case it was not assumed that the electricity in the new houses is used in combination with heat pumps. This option would offer an additional reduction of the space heat demand.

Industry:

Industry uses the remaining fossil fuels. In principle it would also be possible to introduce hydrogen in the industry sector. The rationale to introduce hydrogen in the transport sector was driven by the fact, that hydrogen would offer in the transport sector the use of very efficient fuel cells. If the implementation of fuel cells and of an overall hydrogen infrastructure fails, hydrogen could also be used in most industrial processes. In this case the remaining fossil fuels can be supplied to the transport sector.

4.2.3 Technologies

The technology steps in nuclear fission are characterised by generations. Most of the operating reactors are part of the generation II, the newly developed reactors like the EPR, the SWR 1000, AP1000 are generation III and a major initiative is under way to develop the next kind of reactors called generation IV. The step following generation IV would be the development of an integrated reactor fuel system, which makes it possible to increase the fuel basis and to reduce long lived waste considerable. Generation IV includes fast neutron reactors, which would be able to enlarge the fuel basis considerable. Depleted uranium and thorium could be utilised.

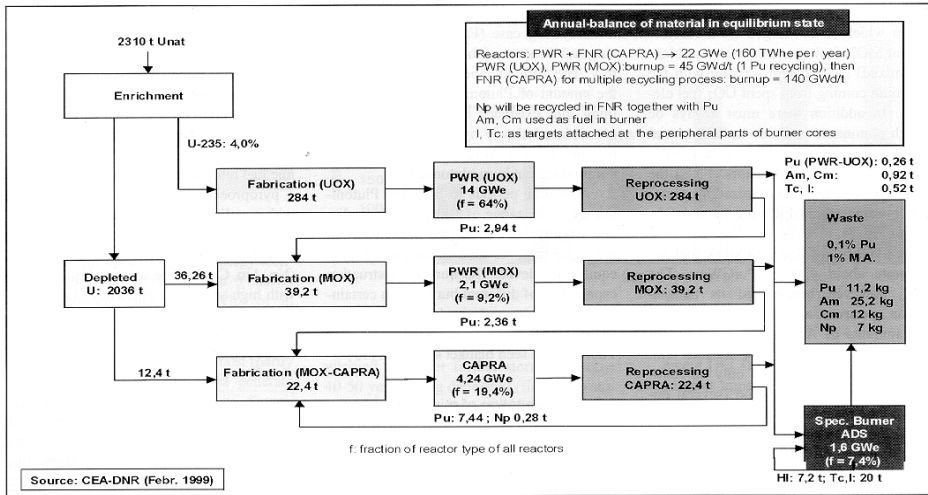


Figure 70: A possible system to reduce long-lived radioactive waste.

The technology programmes in nuclear fission changes considerable in the last decades. In the following investigation we will put the main emphasise on technologies, which will be capable to convert the long lived radioactive waste to short lived waste. Figure 70 illustrates the possible strategy which can be followed here. A family of different reactor and fuel types need to be used. Most of the necessary components are not yet available.

4.2.4 Balance case Europe

In the high nuclear case: nuclear supplies in 2100 more than 60 % of the primary energy and 70 % of the electricity demand. Hydrogen for cars, trucks and busses is also produced by nuclear. The first central observation is, that such a case would use up much more uranium as is even assigned for the whole world in Table res. New fuel and reactor types, like fast breeders, need to be installed to make this scenario feasible.

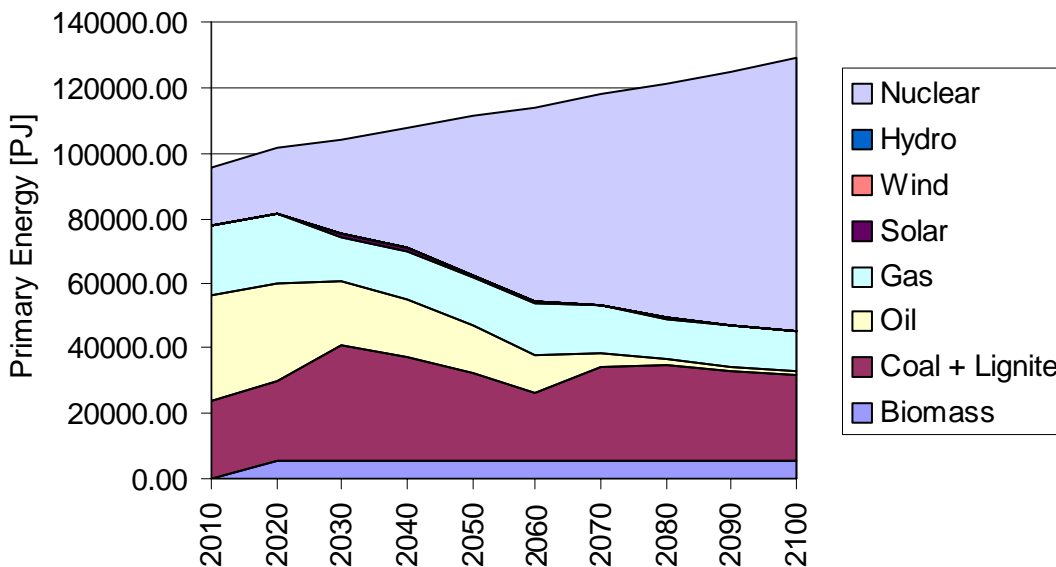


Figure 71: The development of the primary energy supply in the high nuclear case. *It needs to be mentioned right from the beginning, that the resources of uranium would not be sufficient to supply this case.*

From 2050 onwards nuclear starts to supply not only electricity but also hydrogen, which is then used in the transport sector. Candidates for the hydrogen production are High Temperature Reactors (HTR). The massive introduction of nuclear will certainly change the picture of the energy system. One of the changes could be that global energy trade is strongly reduced. Electricity and hydrogen would be supplied in regional centres, closed to the consumers. The only reason for trade could be for example price differences, induced by different environmental standards.

The central issue of the high nuclear case is the investigation of the radioactive waste. The production of large amounts of radioactive waste, which would last for many thousand of years, seems not to be compatible with the underlying sustainability concept. The question is, can the waste be reduced and if yes, how?

A special model was designed and implemented by FZJ to investigate the mix of reactors, reprocessing plants and fuel mixes necessary to reduce Plutonium. One of the sustainability requirements was that no Plutonium stock is build up. The annual energy production of nuclear was calculated with BALANCE.

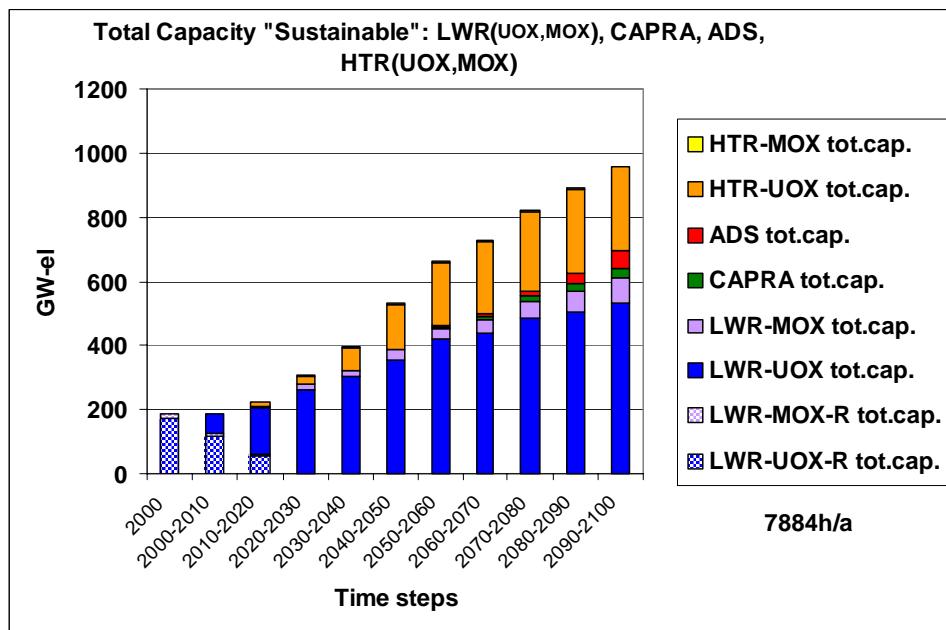


Figure 72: The build of nuclear capacity in the high nuclear case. *In the second half of the 21st century new reactor types like ADS and CAPRA need to be installed to reduce the long lived radioactive waste considerable.*

Figure 72 shows the build up of nuclear capacity in Europe in the 21st century.

A picture of the overall flow of fuels is shown in figure 14. It needs to be mentioned that most of the fuels and processes are not yet available and need to be developed in the coming

decades. Central elements are not only new innovative reactor types, like CAPRA and ADS, but also very advanced reprocessing facilities for the different fuel types.

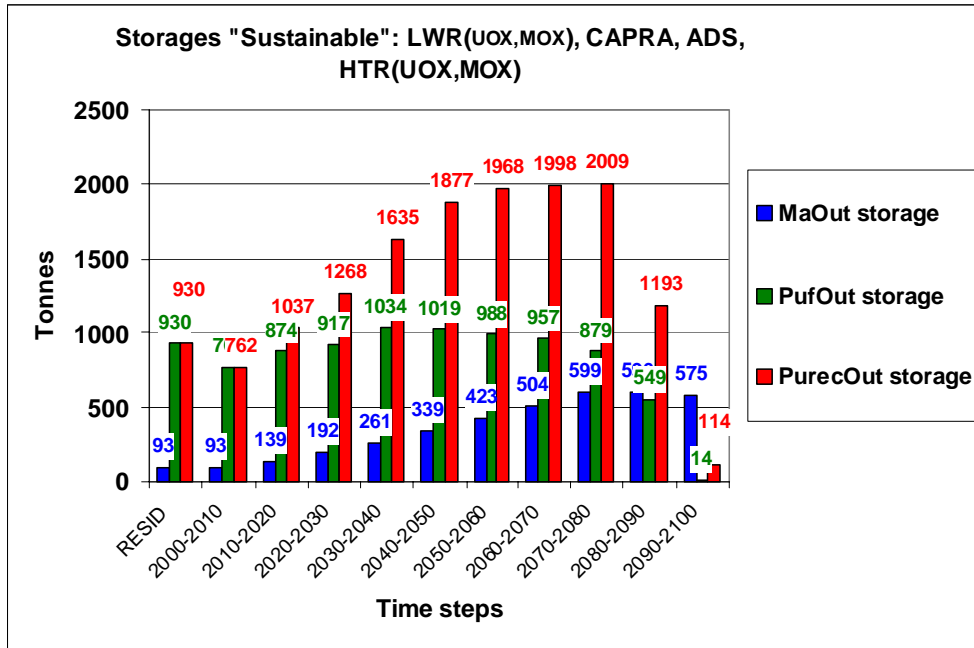


Figure 73: Development of the waste stock for the high nuclear case. Nearly all the plutonium is destroyed at the end of the 21st century.

The development of the stock of plutonium and minor actinides is shown in figure73. The picture indicates that it is in principle possible to reduce the plutonium stock, so that the sustainability criteria would be fulfilled.

The **transport sector** undergoes a still sharper reduction of the demand as compared to the fossil case. This is due to the introduction of still more efficient fuel cells road vehicles directly supplied by hydrogen. A fuel shift from oil to natural gas will also take place. Biofuels will be necessary in small quantities between 2030 and 2050 for the transition towards H² fuel cells.

Traffic

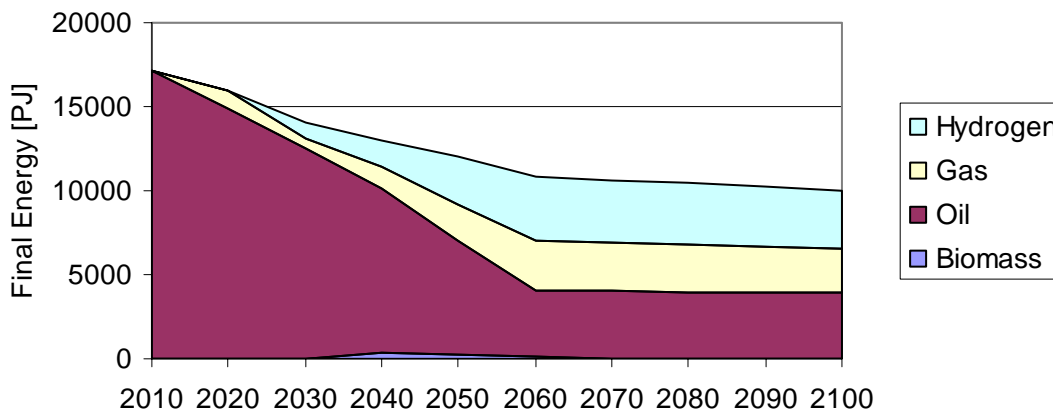


Figure 74: Development of the end-energy demand in the transport sector.

The overall final energy demand of the **residential sector** will peak at roughly 20 EJ before 2010 and then decline steadily afterwards down to 10 EJ in 2050, due to the sharp decrease in the commercial space-heat demand and the substitution of fossil fuels by electricity in thermal uses.

The space heat demand of newly build houses will also be rather low, similar to what has been considered in the fossil case.

Electricity is expected to account for more than 90% of the total final demand of the residential sector at the end of the 21th century.

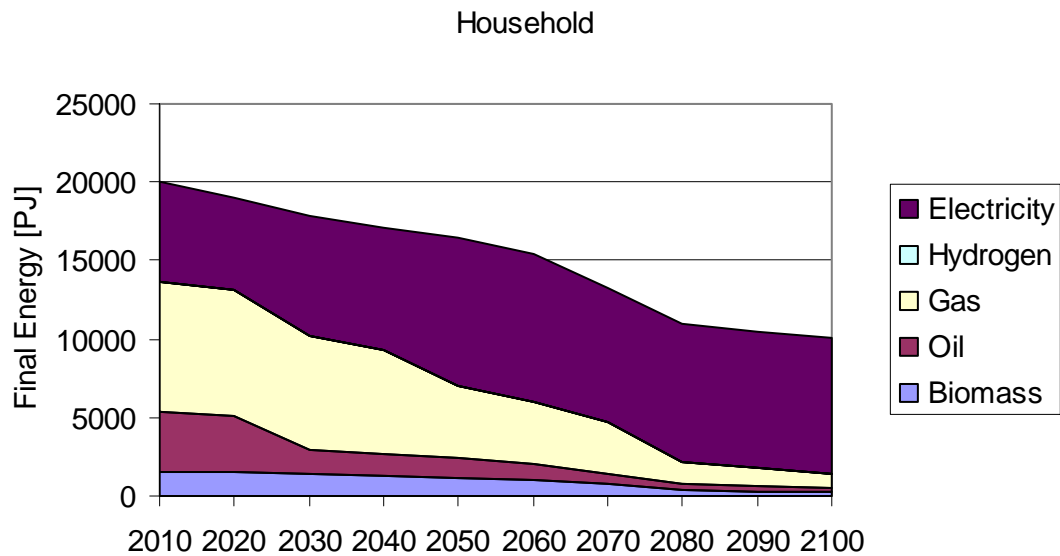


Figure 75: Development of the end-energy demand in the residential sector.

The final energy demand of the **production sector**, industry, construction and services, will continue to grow slowly and regularly over the whole century, from 28 EJ in 2003 up to 41 EJ in 2050, i.e. little less than in the fossil case.

The role of coal will be much lower than in the fossil case, but oil will still be used at the same magnitude, almost exclusively as feedstock. Hydrogen will substitute for coal and gas after 2030. The share of electricity in the total demand will remain roughly stable.

Industry

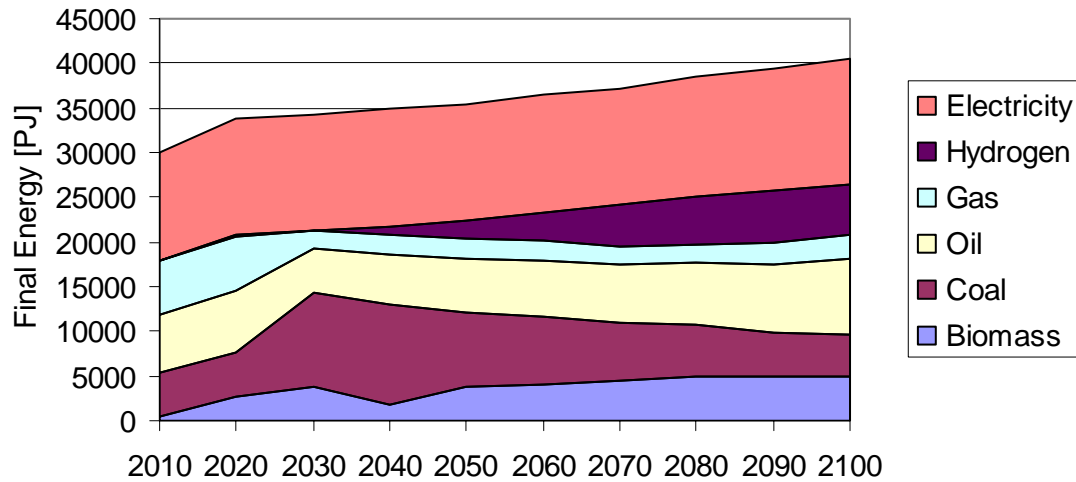


Figure 76: Development of the end-energy demand in the production sector.

4.2.5 Major milestones

The major milestones are shown in figure 77. These milestones can be well distinguished in social and political measures necessary to regain public acceptance, in major R&D measures, in investments in new nuclear capacity and in investments in reactors and reprocessing plants necessary to destroy the long lived radioactive waste.

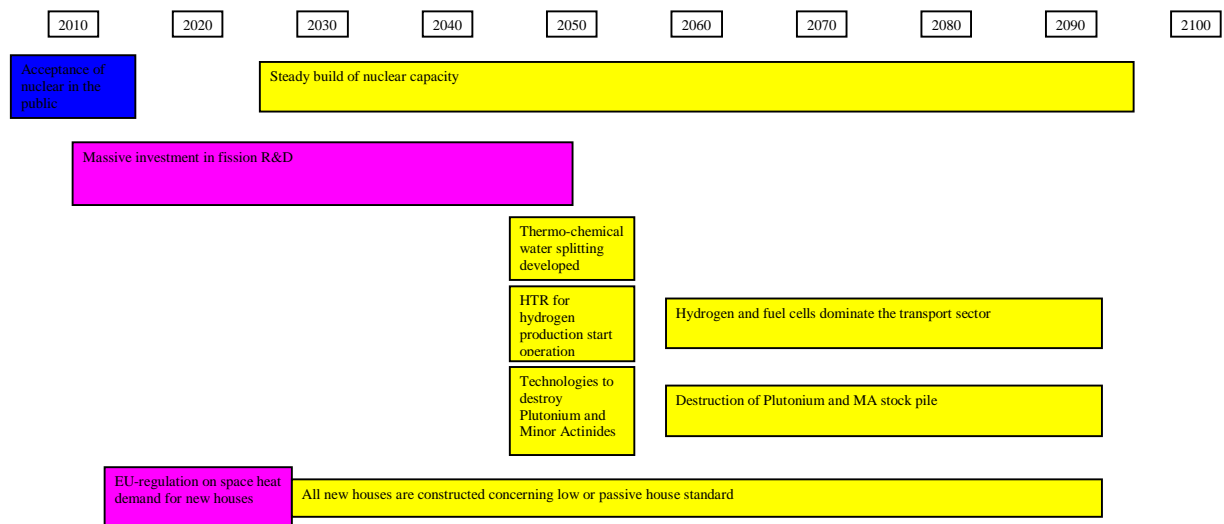


Figure 77: Milestones of the high nuclear case.

Regain of public acceptance

Nuclear energy was the paradigm for progress in the fifties and sixties. Objections were raised in the early seventies and became dominant in the eighties mainly after the accident of

Chernobyl. Before massive investments will be made in fission R&D and new installations nuclear needs to regain the trust of the public. This process is certainly rather complex and would not happen overnight, for the time being it could be only seen as a choice of the kind, picking the smaller evil. Possible arguments in favour of nuclear could be the CO₂ neutrality of the technology (this was certainly one of the major arguments in favour of the new Finnish reactor) and the wish for independence, this might especially be the case if the supply of Russian gas might face problems due to political reasons.

Certainly the young generation shows much more pragmatism in judging nuclear energy than people in the time before did, when the choice in favour or against fission was more a kind of ideology.

R&D Programme

Most European countries developed enormous research capacities to develop nuclear energy. Most of the larger European energy research centres started as placed to develop nuclear. With few exceptions these centres are no longer focused on nuclear but developed rather broad R&D portfolios. The high nuclear case can only be realised if nuclear research gets again a very heavy weight. Certainly it is possible that part of these developments would not be made in Europe, but that the fission R&D community initiates global or at least transcontinental projects to develop the necessary components of a high nuclear case.

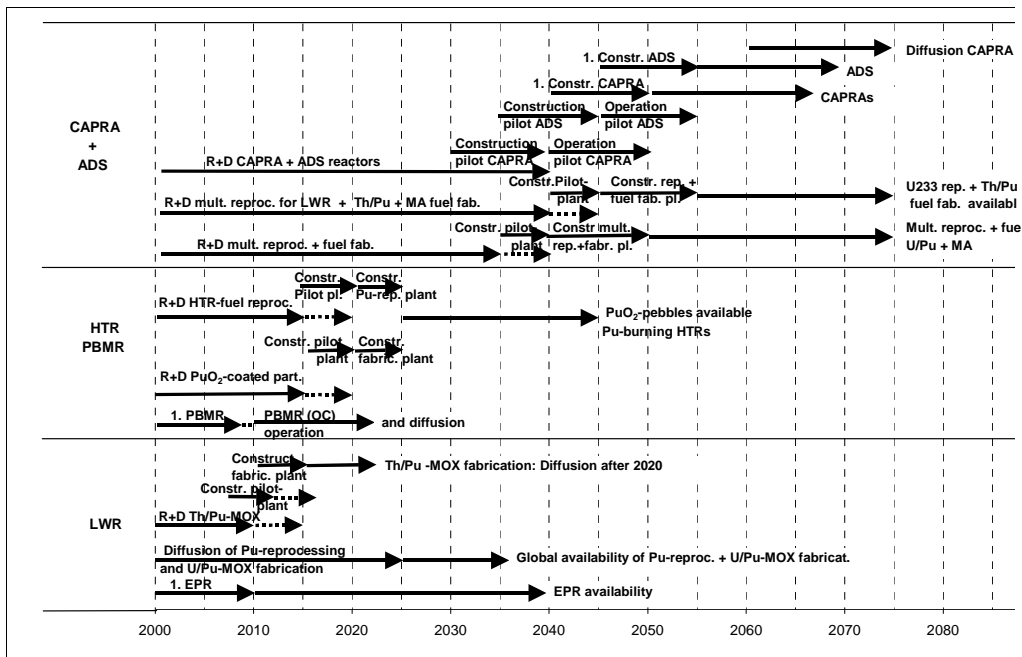


Figure 78: The necessary R&D steps to reach a high nuclear case.

Investment in nuclear capacity

The investment in new nuclear capacity has to start right from the beginning of the 21st century. This bears certainly a risk in respect of the sustainability criteria. Only if the new technologies to destroy plutonium and minor actinides will be developed, the produced waste can be destroyed later on.

The energy industry, especially the electricity industry was liberalised in the last years. This changed certainly the investment behaviour of the major actors. The willingness to invest in capital intensive technologies was reduced. Only if the public perception and the political will would support the action, economic actors would be willing to invest in nuclear. Again this was the case in Finland, where the parliament voted in favour of the new reactor.

The investment in technologies to destroy the nuclear waste would only be realised, if the sustainability criteria would be postulated by legislative measures.

Nuclear hydrogen penetrates into the transport sector

From 2050 onwards nuclear is also used to produce process heat and with this process heat in a thermo-chemical water splitting process hydrogen. The hydrogen is then used in fuel cell cars. The remaining fossil fuels are used in the industry sector.

4.3 Third case: energy flows in nature

4.3.1 The challenges

The energy flows in nature are in principle huge. They are orders of magnitudes larger than the energy demand today and any anticipated energy demand of the future (Soerensen,). Still a number of serious challenges remain, which have to be overcome before renewable energies can supply major fractions of the energy demand.

These challenges are related to the power density of the flows and the related high costs of collecting the energy, they are related to the geographical disparity in the flows and in the time pattern, especially the annual, seasonal and daily variations of solar radiation and wind velocities.

Three different cases will be discussed, a radical picture, which assumes that at least all electricity is supplied by renewable energies, a more conservative approach in which renewable energies supply roughly 50 % of the primary energy demand in 2100 and some reflections of the possibility to reach energy autarky with island solutions.

It is certainly important to remind the reader, that size and complexity of a technological system do influence the possible governance and participation in the major decision processes. Within VLEEM this problem was discussed, but no methodological investigation of the gains and losses in respect to the system complexity were done. The interested reader will find various approaches in the literature (Ingelstam, 1996).

4.3.2 A first glance at a world supplied by renewable energies

Before the analysis of the high renewable case for Europe will be discussed, a rather futuristic view on the outreaching possibilities of renewable energies should be tried. Two central issues for renewable energies are the strong geographic heterogeneity and the intermittent nature of wind and solar power.

A solution to this problem could be a so called “Global Link”. Especially electricity networks are constructed to span over the entire land mass of the globe. A special tool – the TASES programme – was designed to set-up the case. The tool is based on a Geographical Information System and an optimisation model, which is able to optimise energy systems at arbitrary time resolution. To describe the correlation between the various intermittent power sources, time series in hourly resolution were applied.

The idea presented goes back to ideas of Buckminster Fuller articulated in the seventieth. The idea is to span a mesh of electricity transmission lines all over the world and to connect advantageous sites for renewable energy sources with centres of demand and to smooth the stochastic nature of the supply structure by the large geographic spread of the different converters.

The presented analysis was performed with a software tool especially designed for the VLEEM project. The energy system is already today strongly linked in the two major commodities: oil and coal. Gas is transported over distances of more than several thousand kilometres. In future also a link of the electricity system and an emerging hydrogen system might evolve. For sure, 30 years ago the ideas of Buckminster Fuller were only visions dedicated to future decades. But the boundary conditions have changed enormous during the last years. While 30 years ago electricity could be transported efficiently only over about 500 km, new technologies enable economical transport distances beyond 6000 km (Klein, 1994). Losses of 3 % on 1000 km seem to be plausible for high voltage connections. On this basis, electricity transport might be competitive on scales far beyond local tasks. That means, electricity exchange between the northern and southern hemispheres may become feasible on economic grounds.

In the context of a sustainable development, which is often associated with the uptake of renewable energy sources, the development of a global grid becomes a major attraction. The most compelling reason is the opportunity to harvest renewable energy at locations which are, in general, far away from consumption areas. Some examples might be:

- large untapped hydroelectric sites in Latin America, Canada, Alaska, Siberia, Southeast Asia and Africa,
- tidal sites in Argentina, Canada, Siberia, China, Australia and India,
- solar potentials circle the earth: in Mexico, USA, Africa, the Middle East, Russia, India, China and Australia,
- geothermal potential around the Pacific Ocean “Ring of Fire”, in the Rift Valley of Africa, and Iceland.

Due to the fact that electrical energy has an exergy/energy ratio of unity, it is reasonable to transport it also in this form. Therefore a global linked electricity grid might be useful. Another advantage of an electrical connected world is the potential ability to smooth local fluctuations in energy supply sources and in demand usage. One example is the outcome of global distributed wind turbines, which show one of the highest levels of natural variability (figure 20).

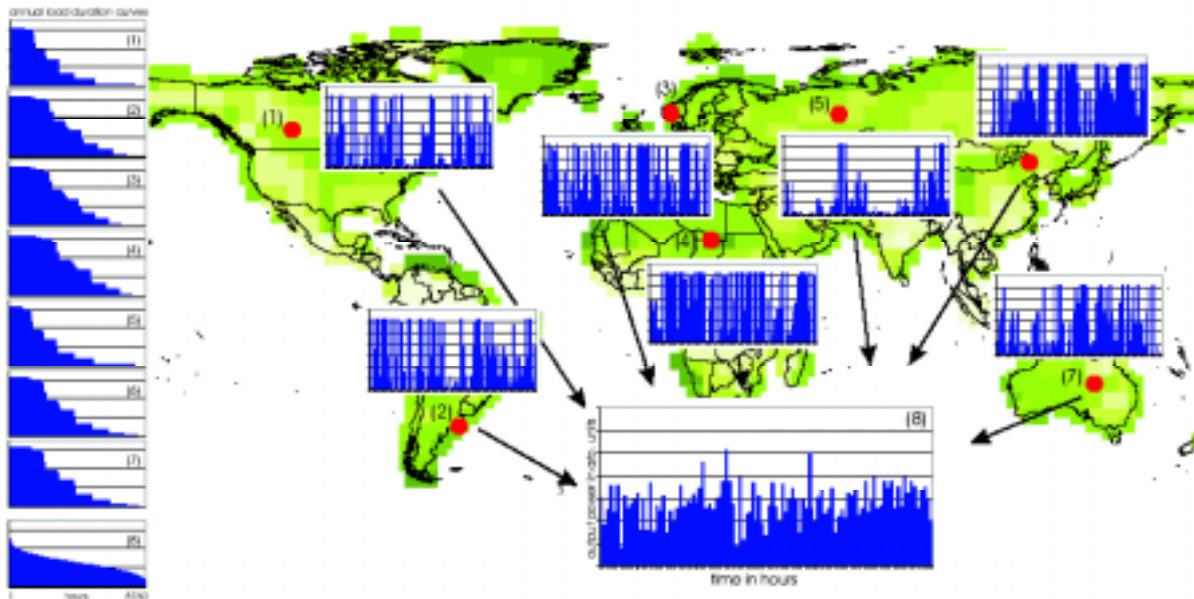


Figure 79: Combined distributed energy harvest for wind power over much of the world in a time scope of 100 hours. Actual fluctuations will tend to be smoothed to an average curve for the globally connected case. Especially in view of the load duration curves for the complete year this can be easily understood (left hand side). The top seven pictures depict the load duration curves for the individual sites marked on the map. Picture 8 on the left hand side represents the load duration curve for the sum of all these curves.

When connected to a global grid, such fluctuations will tend to be smoothed to an average which shows a much smaller deviation in regard to consumption load patterns. Especially the considerations of the corresponding load duration curves support this outcome. They are defined as the sorted load values over a restricted time range. In the merged case this load duration curves show a more or less balanced behaviour. Hence there are a number of reasons that do provide support for efforts to establish a global electricity grid. The *Global Energy Network Institute* (GENI) organisation is devoted to this end (GENI, 2004). In some respects, the world is quite close to a global linkage, when all the existing long haul transmission lines are considered. Given that view, it is reasonable to devote some effort in global models dealing with this very question. To this end, the VLEEM project approach has been enlarged to cater for a global scale. In VLEEM, particular emphasis is placed on the role that renewables can play in such a context. To this end, the world was divided in ten regions as outlined in figure 21. The demand values from the IASA WEC studies (Nacicenovic, 1998) serve as basis for the demand estimates in our scenarios. The IASA WEC data were used since the VLEEM data were not available at the time the analysis was done and like the IASA WEC data the VLEEM demand data present only annual integral values and no resolved time series.

This breakdown is a common one for global modelling and each region is represented by one or two nodes linked to neighbouring regions. The investigation in this special case is restricted to electricity. Furthermore, only solar and wind, and an additional back-stop technology are considered, augmented by storage technologies. This scenario set will be modelled over one complete year in future with an hourly time resolution. The modelling will be by linear optimisation.

Due to the time resolution, a method to preprocess the demand pattern is required. The demand estimates are taken from the aforementioned IASA WEC studies. The prediction for the year 2100, by region, and restricted to electricity is depicted in figure 15.

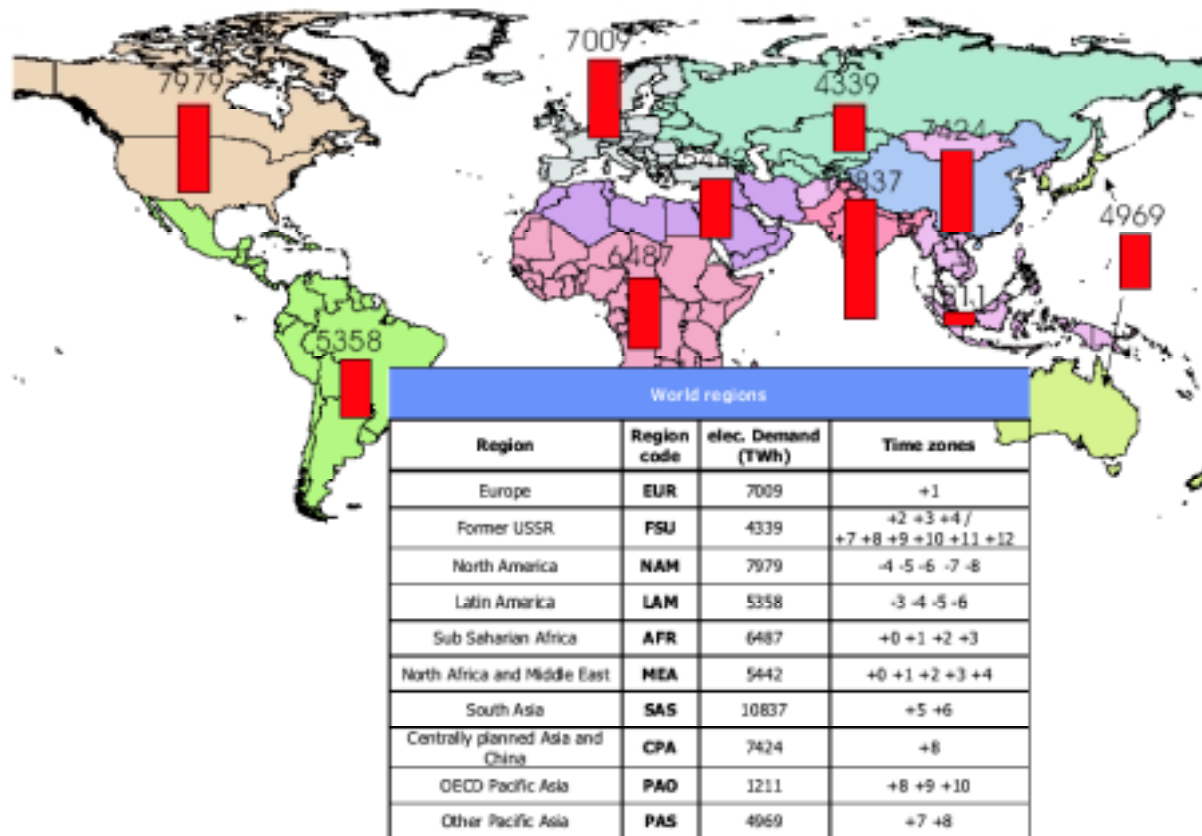


Figure 80: Predicted electricity demand for the year 2100 by region, based on the IASA WEC studies (Nakicenovic, 1998) . The inset table also gives the time zones covered by the various regions relative to GMT.

The values shown in figure 20 are cumulative for a complete year but the model approach needs hourly values. The resultant demand load curves from the UCTE Statistical Yearbook 2000 (UCTE, 2001) are utilised. Merging of this information delivers a rough estimation of the periodical load behaviour in the future. Normalising these curves and shifting them from Middle European Time (MET) (-0100) to Greenwich Mean Time (GMT) now provides the base demand pattern for every modelled region. To get a representative load curve for each region the relevant time zones are elected (see table in figure 21). To gain a region-specific demand load curve, the normalised base curve is shifted by the relative values in figure 21 and these time displaced curves will be then merged for each region. In addition, the demand patterns situated in southern hemisphere are shifted by an additional number of 4380 hours (half of one complete year), just to compensate for the fact that the seasons in the southern hemisphere are shifted by half a year. Of course, this procedure will not fit the real demand pattern in 2100, but it will serve the purpose, that is to get a rough estimate of future electricity demand distributions, one which permits modelling with a high temporal resolution.

In addition to these time series which found input into the GLOBAL LINK scenario the model assumptions for the costs of wind and solar PV are taken from (Lako, 1998). The interaction between storage and transmission lies at the core of this scenario set. The cost values given for these two technologies are oriented on estimates in (VDI, 1994) and (Amos, 1998). The resulting model behaviour in terms of storage versus transmission is of particular interest.

In regard to solar and wind power opportunities, not only is an average pattern for each region required. Each node is considered to have single load behaviour and a geographic position. To combine this with the consumption load pattern, each wind or solar site is connected to a demand point. Actually to the one, that is closest.

In addition to the load behaviour of each interconnecting transmission line, an additional result of the linear optimisation will be the optimal capacity for each single solar or wind location. The following limitations are added to keep the results realistic. First, only 0.5 % of the available global surface can be utilised to harvest solar energy through PV. And second, wind power is restricted to 1.25 GW per 10000 km².

To simplify the optimisation process, an informed pre-selection of suitable solar and wind power locations is carried out. In terms of criteria, only solar locations with an aggregated insolation of 1700 kWh/m² and wind locations with more then 3000 full load hours are "made available" for this modelling set. In addition, the modelled time steps are reduced from 8760 values (each hour a year) to 2184 values (only every fourth week of a year is regarded). This represents a good compromise between lose of accuracy and obtained modelling performance.

Purpose of this particular scenario set is to sketch out the geographical counteractions on a global scale, in the context of the restrictions asserted by the model definition.

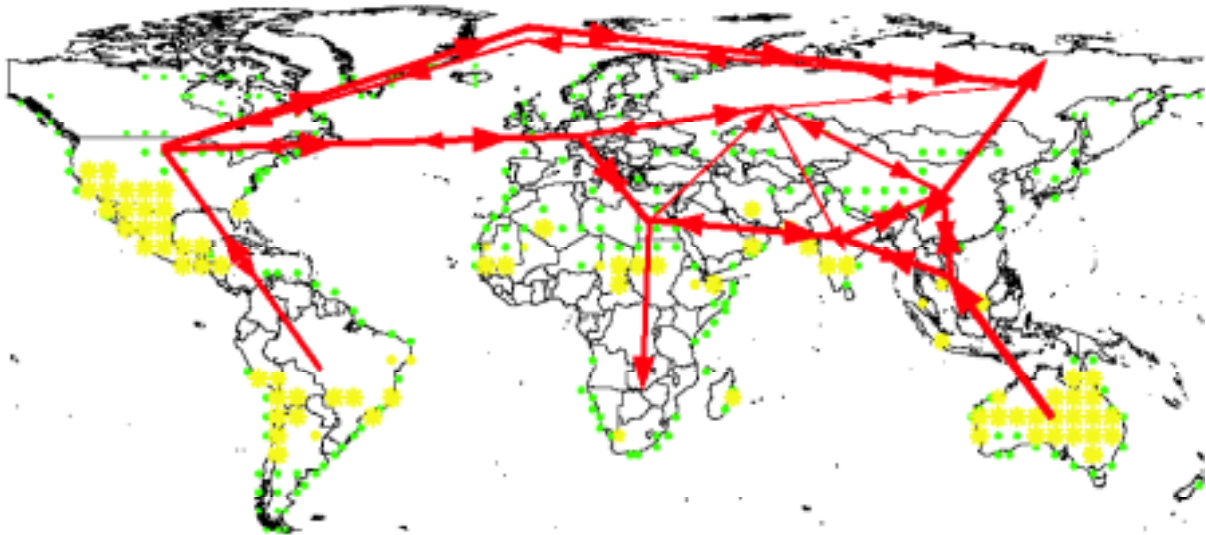


Figure 81: Visualisation of the model-selected facilities by region. The transmission lines are shown in red, activities using arrow weights, solar power locations as yellow sun symbols and the selected wind energy sites as green dots of varying size. The presented scenario has no fusion power and no storage. The wind power is restricted to 1.25 GW/10000 km². Solar power is constructed north and south of the equator to make seasonal exchange between these regions possible.

One self-evident result is a major energy flow to the regions of expected high consumption of south-east Asia, China, and India. Of interest is the fact that especially Australia contributes in this scenarios, next to the utilised potentials nearby the consumption locations, to the global energy consumption coverage. This behaviour is founded on the fact that a huge potential of wind and solar energy is mainly localised in Australia, but subject to a high fluctuation that requires huge storage to compensate. In the event of such storage being installed, the widely distributed energy sources spanning several time zones in west and south will become competitive due to the improved intertemporal match provided for by combination. In most situations, no single technology can introduce major system benefits alone. Rather, it is the interplay of new opportunities in the context of the remaining system and through well managed integration that enables latent system benefits to be uncovered. In the case just presented, this required a portfolio of diverse technologies including storage and transport and a procedure for identifying optimal upgrade responses.

Fur different scenarios were defined, with and without special restrictions on the maximum capacity of wind power and with and without electricity stores.

Table I. Results of the eight scenario calculations. The introduction of fusion relaxes immediately the pressure on storage and transmission capacities and reduces – as expected – the required installations of wind and solar power.

	No Store, high solar	With Store high solar	No Store, high wind	No Store, high wind
Grid Capacity [GW km]	1.6E+08	1.7E+07	3.0E+07	1.1E+07
Grid Utilisation	0.20	0.51	0.22	0.40
Solar Capacity [km ²]	123833	78124	10596	8335
Wind Capacity [GW]	8659	8160	19182	16554
Storage Capacity [TWh]	0	217	0	53

Table I: Results of the global link scenario for various basic assumption.

The two renewable technologies wind and solar show different behaviour especially in respect to necessary storage and transmission capacity. In case no storage capacity is installed the case which is mainly supplied by solar requires a factor of five more in the transmission capacities compared to the case with a large fraction supplied by wind. If storage capacities are available, the high wind case requires only a quarter of the storage space compared to the high solar case. These issues are of special interest in their own and are discussed more in detail elsewhere (Biberacher, 2004).

The whole investigation is rather sketchy and futuristic but it clearly demonstrates that renewable technologies are in principle capable of supplying large fractions of the energy demand, if a very sophisticated global electricity infrastructure is set-up.

4.3.3 Final energy carriers

The case discussed here is less futuristic. Renewable energy sources do not cover everything but still up-to 50 % of the primary energy in the year 2100. The design of the case is slightly different from the example just mentioned, not wind and especially solar power play the dominant role, but biomass will. This is certainly an assumption, which can be debated. The underlying assumption, namely that biomass can supply roughly 20 EJ in Europe to the primary energy, is certainly optimistic. Still progress in agriculture and harvesting technologies, make such an assumption at least not completely unrealistic. Renewable energies penetrate all sectors, biomass in the transport and industry sector, PV and wind in the electricity sector and solar thermal in the heat and electricity sector.

Transport sector

The transport sector is assumed to undergo three major transitions. Increase in car efficiency by introducing hybrid cars, shift from gasoline to bio-fuel and then to fuel cells fuelled by hydrogen produced from biomass. In the modelling the route to bio-fuel is kept open for the time being. It was assumed that biomass can be converted with an overall efficiency of 60 % to bio-fuels and later with 70 % to hydrogen.

Housing sector

The space heat demand is again expected to decrease considerable, like in the cases before. The only difference is that it is expected that solar power covers 25 % of the heat demand of the stock in the course of the 21st century.

Industry

Industry uses part of the remaining fossil fuels, but also biomass. A problem is certainly the plastic production, which is currently based on oil. The biomass is not sufficient to replace all the oil products from the plastic production.

Electricity is produced by a mix of PV, imported solar thermal electricity, wind and as back-up mainly natural gas. This mix makes it possible that no seasonal stores a necessary yet.

4.3.4 Technologies

Most of the technologies to convert energy flows in nature to useful energies are in principle known for quite some time. The only exception is photovoltaic. This technology was developed in the early sixties.

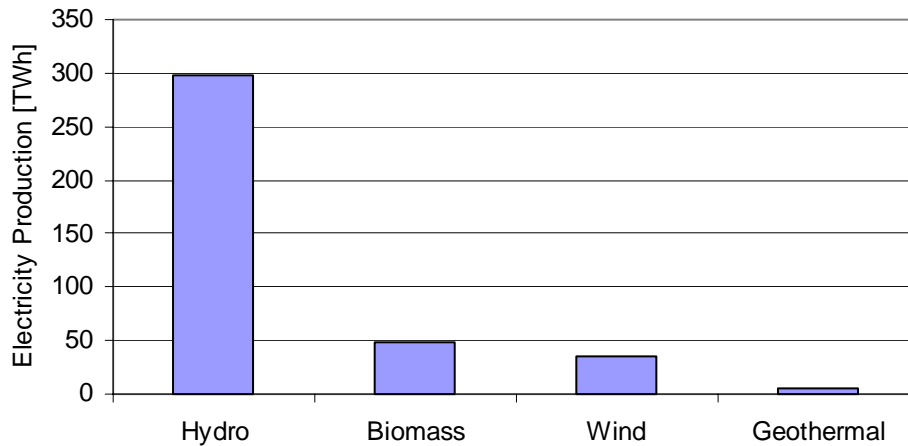


Figure 82: Electricity production from renewable sources in the EU25.

With the exception of geothermal energies, solar is the primary energy source of all energy flows in nature. A lot of people expect (Haefele, 1981) that solar will play the dominant role in a world supplied mainly by renewable energies. Only a very small fraction of the world primary energy was supplied by solar technologies in 2000. The conversion of solar power to commercial energy carriers can be done by various technologies, one route is to use the heat produced by the radiation, the other is to use the radiation itself to produce electricity in PV-cells. Only in focused systems temperatures can be achieved, which can be used to produce electricity or even split water to produce hydrogen (the later process seems only feasible with the help of catalysts, while otherwise temperature above 2000°C need to be reached.) All of these technologies are in principle developed and find applications either in niche markets or if they get special financial support.

Biomass

Roughly 4 million years ago men started to master fire. Utilisation and cultivation of fire was one of the most important cultural achievements of men. Although anthropology is unable to deliver a clear proof, the technology of fire seems to be a key element in the diffusion of men all over the planet. Biomass plays still in many parts of the world a key role as energy source, biomass dominates the informal non-commercial energy sector. But certainly this kind of use of biomass can not be considered sustainable: 1) more biomass is used than grows every year, 2) the common use of fires in houses damages human health.

Wind

Estimates including on- and off-shore wind potentials show that wind power might emerge to one of the dominant future electricity sources. In some European countries namely Denmark, Germany and Spain wind energy plays an ever growing role.

Hydro power

It delivers with roughly 17 % of the global electricity supply. Within Europe most of the potentials are used, this is certainly not the case for Europe.

More technologies can be envisioned like special power towers: using up-wind or the falling wind. Various technologies are under discussion to utilise geothermal energies. Also

As was shown already in the first example in the case of renewable energies the total system design becomes extremely important and needs very special attention. Technologies to transport and store electricity gain importance and need special considerations in the R&D programmes.

4.3.5 Balance case

In the balance case roughly 50 % of the primary energy is supplied by renewable energy sources. Biomass covers 25 % of this fraction, solar in Europe 11 %, wind roughly 7 %. Electricity from solar thermal power plants is imported to Europe. Nuclear energy is expected to fade out at the year 2100.

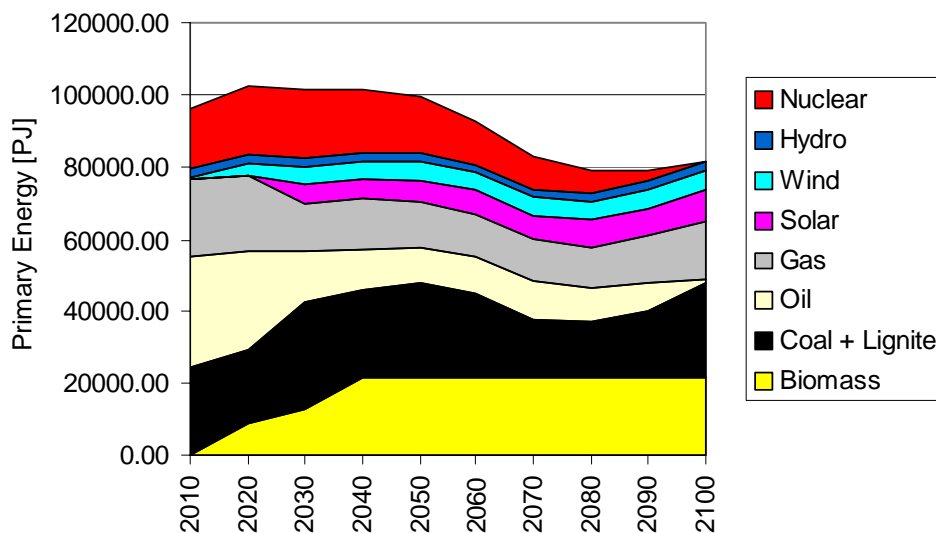


Figure 83: Development of primary energy carrier.

The most important renewable primary energy carrier is biomass. The use of biomass in the case is shown in figure 84. The first application, which dominates the market today is the supply of heat. This application becomes less important in the future. Biomass is the mainly used for biofuels and later for hydrogen production and direct use in industry, not at least as feedstock.

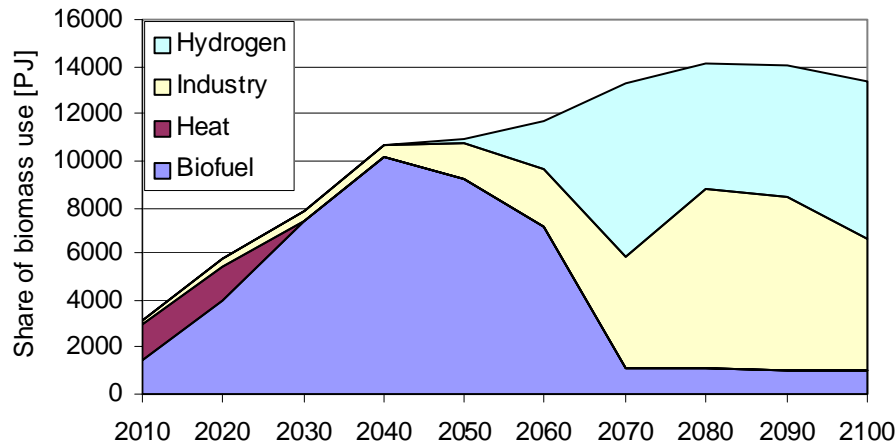


Figure 84: The figure shows the use of biomass in the different sectors.

The **electricity sector** undergoes major transition. In the year 2100 wind and solar are the most important electricity sources. The rest of the system follows this development. Classical base load plants disappear and are replaced by fast load following but still efficient gas power plants. A more in depth analysis of this case would need to investigate the possibility that the gas is step by step replaced by hydrogen, which is produced by the PV and wind power plants in off-peak demand hours.

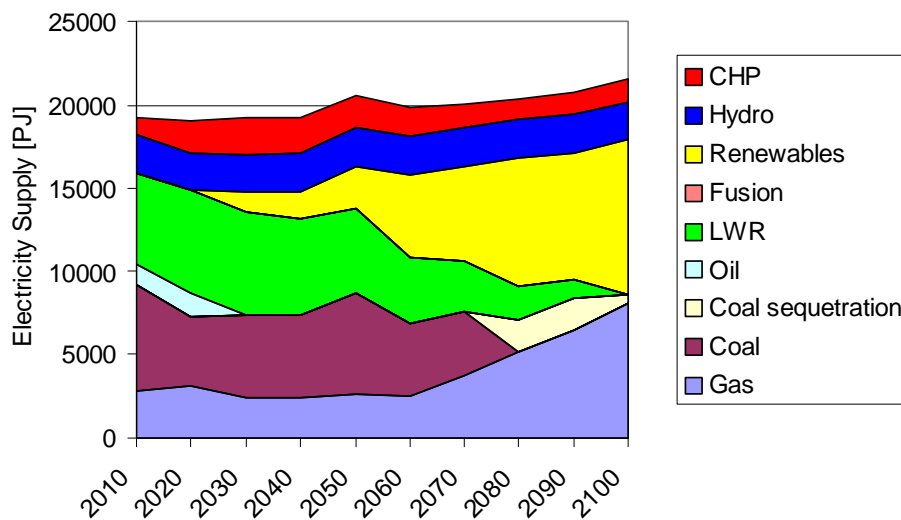


Figure 85: The electricity sector is dominated by solar, wind and gas.

The shifts in the **transport sector** are significant. Strong reduction in demand by first the introduction of hybrid cars and second the introduction of fuel cells and two major shifts in the fuel: first from gasoline and diesel to bio-fuel and then from bio-fuel to hydrogen also of biogenic origin.

The final energy demand of the transport sector will then decrease from 16 EJ in 2003 down to less than 6 EJ in 2100.

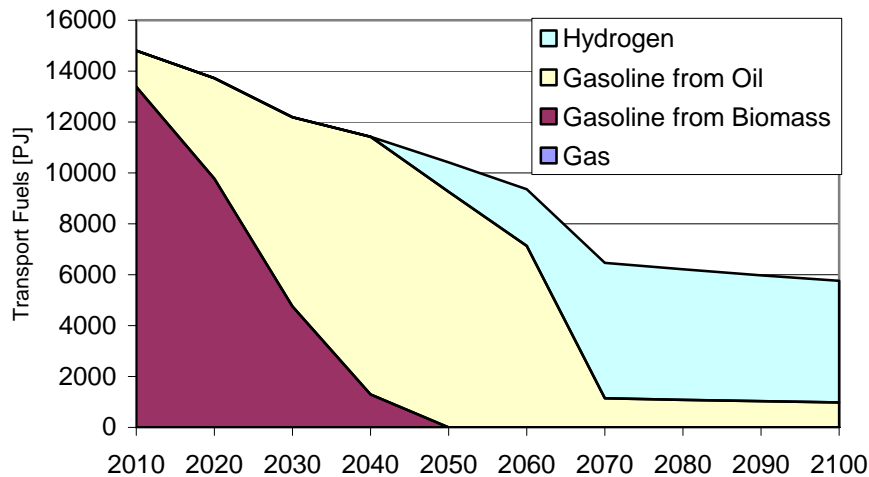


Figure 86: Development of the end-energy demand in the transport sector.

The overall final energy demand of the **residential sector** will peak at roughly 21 EJ before 2010 and then decline steadily afterwards down to less than 10 EJ in 2050, due to the sharp decrease in the commercial space-heat demand (huge development of low energy houses) and the substitution of fossil fuels by electricity in thermal uses. Electricity is expected to account for more than 70% of the total final demand of the residential sector at the end of the 21th century, a large part of it being supplied by photovoltaïcs (solar roofs) in decentralised electric systems.

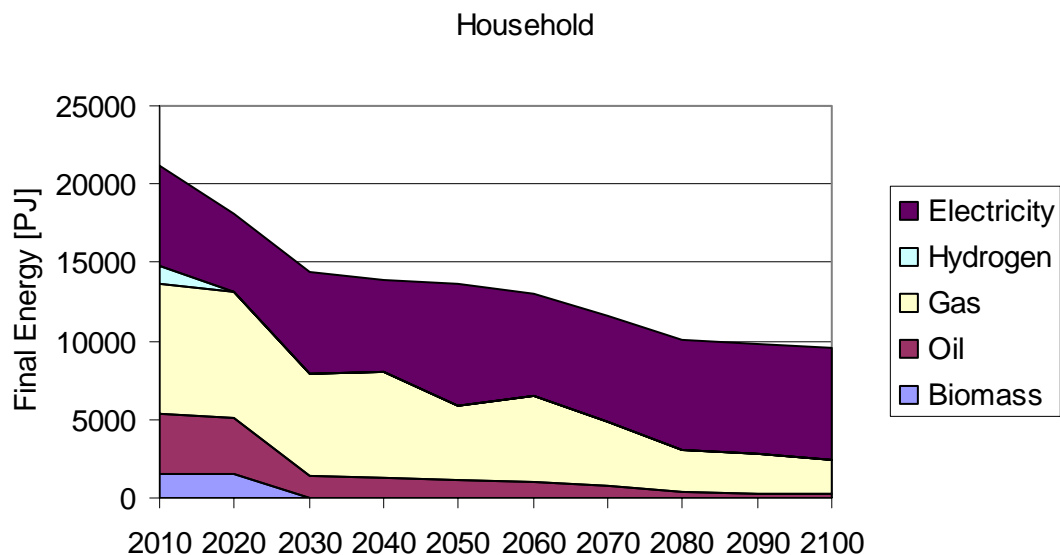


Figure 87: Development of the end-energy demand in the residential sector.

The final energy demand of the **production sector** will continue to grow slowly and regularly over the whole century, from 28 EJ in 2003 up to 40 EJ in 2050, i.e. little less than in the nuclear case.

The role of coal will be much lower than in the fossil case, but oil will still be used at the same magnitude, almost exclusively as feedstock. Hydrogen will substitute for coal and gas after 2040, but in a much lower proportion as compared to the nuclear case. The role of biomass will be much higher than in the other cases, in particular in substitution for coal during the last 30 years of the century. The share of electricity in the total demand will remain roughly stable.

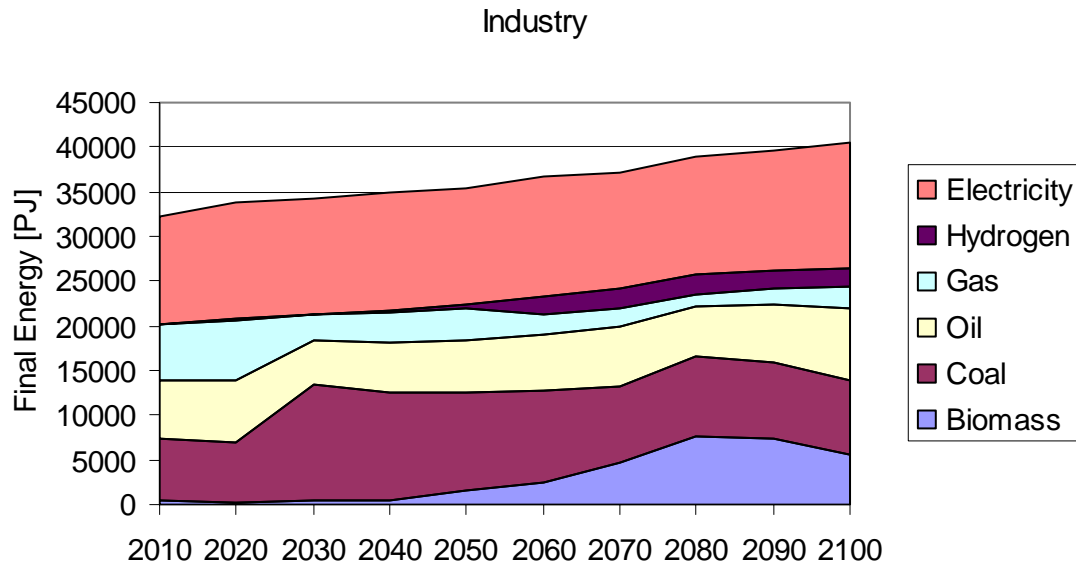


Figure 88: Development of the end-energy demand in the production sector.

4.3.6 Major milestones

The most important issues would be an efficient supply of biomass and technologies to convert the biomass to end-energy carriers like bio-fuels, feedstock for industry and later on hydrogen. In the electricity sector wind and solar technologies need to become competitive within the next fifty years. Efficient gas plants need to be developed to balance the intermittent supply of wind and solar power.

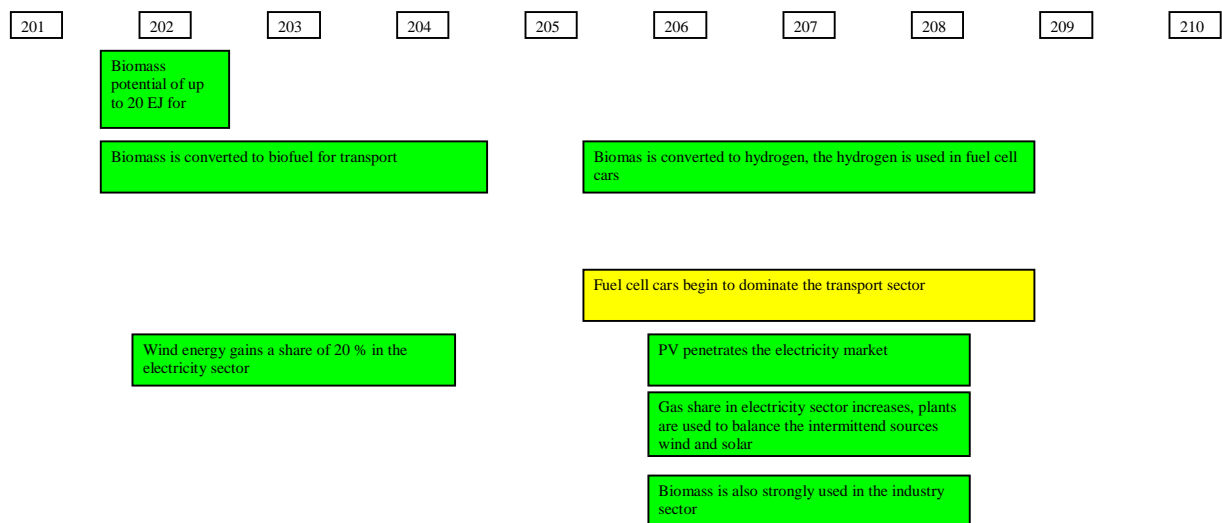


Figure 89: Milestones of high renewable case.

In case of the global link the most critical issue is the development of cheap and efficient transmission cables, with low losses and very high power densities. A possible candidate would be superconducting cables.

4.3.7 Some reflections of solar PV as major source of energy for the housing sector

The wish to reach autarky in the energy system, autarky meaning that small units of a few houses or even individual houses are self sufficient is followed since some time. In pilot projects so called “Zero energy houses” were developed and proved their technical feasibility. Certainly this root seems to be a possible direction for the household sector in sub-urban or rural areas. City centres reach power demand densities, which are unlikely supplied by the energy flows which can be collected in the region. This is also the case for most industrial processes. These processes need power densities, which need some central energy collection and supply system.

The possible realisation of zero energy houses in certain regions depend on various factors:

- the final cost of PV cells, will they become so cheap that even in winter times the peak demand can be supplied by the PV electricity
- will the demand of the electrical appliances be so low that again the electricity cost does no longer matter
- will seasonal energy stores become available even for the household sector
- the seasonal variation is less dependent

The major R&D issues in this respect are cost reduction in PV and new storage concepts.

4.4 Central conclusions:

As mentioned already at the beginning, the task of VLEEM was to establish a methodology and to work out first examples. This was certainly fulfilled. The examples show that the methodology is in principle adequate to discuss R&D questions, the examples themselves are of course inadequate to draw major conclusions. Therefore it is not possible to draw major final conclusions. Still a few items should be mentioned, which seem robust:

- early regulative measures in the housing sector are important
- future R&D projects should put more emphasise on the system development and not only the development of individual components
- electricity transmission lines might become important in all pictures of the future

To reach any of the sustainable future requires action already today. Current energy R&D measures are not sufficient.

4.5 Literature:

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5. General Conclusions

5.1 *Modelling energy on the very long term*

Any scenario analysis for the very long term – and hence also the VLEEM projections for 2100 - is inevitably dependant on the knowledge of today and the dynamics experienced in the last decades. Certainly, major scientific discoveries will occur during the next hundred years, which may have potentially tremendous consequences on the technology paradigm and the social organization worldwide, which cannot be modelled from today, and which could jeopardize some of our conclusions.

To some extent, the VLEEM project has proven that it is possible to give a quantitative assessment of the energy systems on the very long term, with an acceptable level of consistency between demographic, macro-economic, socio-cultural and technology dimensions of the energy problem, which is the pre-requisite for some robustness to the assessment. Parameters which have not or hardly been used for long-term modelling so far and which have been introduced in the VLEEM model are the level of information of societies and the concept of time budgets.

Two major conclusions can be drawn from the VLEEM project on energy modelling for the very long term.

- From the demand side, it is confirmed that changing the modelling paradigm as compared to usual demand models brings a very different vision of what could be the challenges of supplying conventional energy to the final consumers by the energy system at the turn of the century; this has been shown to be particularly true for transport. Being less dependant on the existing technological base and on the rather short historical evolutions for which data are available and reliable (more or less 30years), the new modelling concept gives more emphasis on very long term trends, more closely related to the fundamentals of the behaviours of human beings.
- From the supply/demand integration side, it is confirmed that there is a strong need to adapt the modelling structure to the dominant technology paradigm of the energy system: an energy world with a dominant position of the renewables raises quite different modeling problems than an energy world dominated by fossil fuels or nuclear; of course, there is still a need of a comprehensive representation of all the links of the energy system with any kind of Reference Energy System modelling package, but this proves to be far from enough.

5.2 *Sustainability or ...?*

The investigation of the needs of energy services in relation to the development of the demography and education all over the world clearly shows that the rise in the needs of energy services worldwide will be tremendous – namely more than a factor 3 between 2000 and 2100 - if the obstacles to the emancipation of the people and the development of economies –from the policy or the financial sides – are progressively removed (as they are currently removed in an increasing share of the most populated developing countries).

From this simple observation, two drastically different development pathways can be singled out:

- first, these obstacles are eventually removed, because the social and economic dimensions of the sustainability prevail worldwide; then to meet these needs with limited natural resources and limited absorption capacity of the earth for pollutants and wastes would raise increasing and potentially tremendous challenges, whatever technology paradigm(s) will dominate the energy system at the turn of the century; this would certainly reduce the range of possibilities and force necessary changes, in particular in end-use technologies and behaviours, and more generally on energy efficiency;
- second, these obstacles are not removed, or only partially, and a large of the world population continues to live in poverty and precarity without interacting seriously with the formal energy system at the turn of the century; the challenges with regard to natural resources and environmental constraints are released, and the range of possibilities to cope with the environmental dimension of sustainability widen substantially.

VLEEM case studies have been designed to investigate the first view only, on the basis of the sustainability principles adopted in the project.

The results, although limited for the moment to Europe, clearly indicate that indeed all the dimensions of sustainability can be fulfilled at once at the turn of the century, but under strict conditions with regard to the evolution of the technology and organization at the level of the final consumers, as well as the necessity of some major breakthroughs in the energy supply technologies whatever the dominant paradigm.

For instance, sustainability cannot be reached in any case without a revolution in building concepts (zero energy house becomes a pre-requisite, not an utopia), or without a huge development of fast trains for long distance movement up to 1500 km, for passengers and freight. Mastering the transport of electricity over very long distances at acceptable losses and costs appears also a pre-requisite in all cases, as well as the daily and seasonal storage of huge amounts of electricity at acceptable costs.

The primary energy which would be needed in 2100 to fulfill the needs of energy services of Europe in the mid-pop scenario is expected to range between 80 and 130 EJ in 2100, according to the technology paradigm, against 80 EJ in 2000. Transport energy demand would range between 6 and 11 EJ, against 16 EJ in 2000.

5.3 Conclusions for energy RTD

The paradox of the VLEEM results at the stage is that they give quite a few keys for investigating major energy RTD issues for Europe, but at the same time they show that Europe becomes a relatively small actor on the world energy scene at the turn of the century, having a clearly smaller share on global environmental dimension of sustainability worldwide.

This leads to the first key question with regard to energy RTD priorities for Europe: solving the European energy problems in a sustainable way, or leading a worldwide industrial development of technology solutions likely to solve the energy problems worldwide in a sustainable way?

In any case, Europe needs to embark on critical reflection about its long-term role and ambitions in the energy field. In the further course of the century the need for focussing on core technologies and competences in Europe may become obvious. Today, however, the available insight does not support such a decision.

The various case studies investigated in this research have indicated obviously different road-maps for RTD and development of the different technologies involved in the various technology clusters, which would correspond to different priorities for EU energy RTD strategies. It is not the role of the VLEEM consortium, neither to decide which technology cluster would be preferable at the turn of the century, nor to propose to priorities in energy RTD which would make sense only in relation to one particular technology cluster.

But, as explained above, a set of conclusions can be drawn as regard the technology evolution which will be necessary **in any case, for any technology paradigm for the very long term**. These conclusions certainly indicates priorities in “no regret” energy RTD strategies of the EU.

Here are our main conclusions in this regard:

- a) Very low energy buildings is a top priority: this covers at least the following areas for RTD:
 - a. New materials and concepts for building shelters insulation and use of solar radiation
 - b. PV roofs and electrical devices performances consistent with PV roof systems specification
 - c. in addition, ample attention has to be given in the correct construction of low energy buildings, most of the time reality is different than the paper design of such buildings. A lot of misunderstanding and even incorrect assumptions are currently circulating, resulting in a over/underestimation of the impact of low energy measures. Monitoring and in-use measurement programmes and tools are hence equally important and suitable for R&D
- b) Combined Electricity-Hydrogen systems:
 - a. Production: thermo-chemical, high efficiency electrolysis
 - b. Storage
 - c. Fuel cells, distinguished between mobile and stationary; or power or heat driven
 - d. Reformers (Gasoline -> H₂ or methanol-> H₂) may be important in the transition phase towards a (complete) H₂ society
- c) Electricity technologies:
 - a. Transportation of electricity over very long distances (in combination with hydrogen at very low temperature?)
 - b. Storage: hourly, daily, weekly, .
- d) Bio-technologies for energy:
 - a. Biofuels from woody biomass (lignocellulosics)
 - b. Biomass as feedstock and (construction) material substitute

Annex 1 : Accounting for sustainability in VLEEM**Annex 2 : Detailed results on bulk materials****Annex 3 : Monographs***Annex 3.1 Monograph on Biomass**Annex 3.2 Monograph on Hydropower**Annex 3.3 Monographs on Fuel cells**Annex 3.31 Fuel cell for stationary applications**Annex 3.32 High-temperature fuel cell systems**Annex 3.4 : CO₂ capture and sequestration***Annex 4 : Summary description of the sub-models of VLEEM**